AMERICAN TELEGRAPH PRACTICE

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A COMPLETE TECHNICAL COURSE IN MODERN TELEGRAPHY, INCLUDING SIMULTANEOUS TELEGRAPHY AND TELEPHONY

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PREFACE

In this work the aim has been to give a detailed exposition of the various systems of telegraphy in use in America at the present time, together with a complete description of modern methods of operation, and an extensive compilation of the formulae used in practical telegraphy.

One occasionally hears it remarked that since the practical introduction of the quadruplex about thirty years ago there have been no important developments in telegraphy, but those who have been engaged in the work of improving telegraph apparatus and operating methods are well aware that even since the last American book dealing with this subject was written several years ago, material progress has been made in several directions.

The fact that to-day eighty telegrams per hour are handled over a single Morse outlet where ten years ago half that number in the same time was considered good performance, and that during the same period the time of transmission of a telegram between cities remotely separated has been reduced at least one-half, cannot but be regarded as convincing evidence that vast improvement has taken place.

One factor that has contributed largely to the improvement in the service is the increasing technical knowledge of the men engaged in operating the plant; and this, in spite of the fact that the production of technical telegraph literature has not kept pace with the actual development of the art.

In the present work the author has incorporated all of the elemental essentials of the general subject as well as all of the new departures which have made for betterment, and an attempt has been made to treat the various divisions of the subject in terms that should make it possible for the student, by due exercise of diligence, to qualify himself for the most advanced positions in the service.

Incidentally, it might here be stated that it is no longer possible for the telegrapher to make much headway in the service without an understanding of arithmetic and elementary algebra, and, while usually mathematical formulae are regarded as being incomprehensible, by those who have not had the advantages of high school education, the author believes that as herein employed and worked out, all of the required mathematics may be mastered without difficulty. The text of the work is based, to a large extent, upon a series of lectures given in the evening technical schools in connection with Columbia University, New York, during the past year, and as none of the students, all of whom are telegraph and telephone workers, had unusual difficulty in understanding the mathematics of the subject, it is believed that the

problems submitted in the present work will be found no more difficult to the average student of telegraphy.

The fact that the controlling telephone interests have recently obtained control of one of the large telegraph companies indicates that it is realized that the telegraph will, in all probability, remain for a long time to come the only available, practicable means of taking care of the greater share of long distance traffic. Joint operation of lines for telephone and telegraph purposes simultaneously is being extensively practiced, and that portion of the present work dealing with the complementary operation of the two established methods of communication describes the latest approved appliances and circuit arrangements from a telegraphic standpoint.

In deciding upon the subject matter, care has been taken not to omit any of the features with which operators, wire chiefs, quadruplex attendants and repeater attendants are concerned.

The chapter on circuits and conductors illustrates in detail the principles and laws of each form of electric and magnetic circuit used in telegraphy.

The chapter dealing with speed of signaling contains mostly new matter of the greatest importance in maintaining reliable high speed telegraph operation, while other chapters describe the latest types of duplex, quadruplex, and automatic equipment used by the Postal Telegraph-Cable Company, the Western Union Telegraph Company and the larger railroad telegraph systems, also up-to-date methods of circuit concentration in large offices.

D. McN.

New York
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INTRODUCTION

Although the nature of electricity is not definitely known, several different theories have been advanced by physicists within the past century and a half, with the object of attempting an explanation of the causes of the various phenomena which are called electrical.

Most of the old ideas relating to the nature of matter have been abandoned within comparatively recent years. It is, for instance, now believed that matter is not inert, but that in all probability it is endowed with potential energy.

Present knowledge points to the conclusion that the all-pervading ether is in some manner saturated with energy, available for employment, however, only through the agency of matter, which transforms it into familiar forms of energy such as heat, electricity, etc.

The electromagnetic theory of light, now generally accepted, teaches that energy from the sun travels through the intervening ether to the earth in the form of ether waves. Thus, when it is considered that most of the natural energy at our command could, through the properties of heat, light, and other effects, have been identified as electrical energy in one stage of its transfer—through the ether—the natural hypothesis which suggests itself is that the ether is the seat of electrical forces. Indeed, the relationship existing between the ether and what is termed electricity is so close that it would seem that no hypothesis can be regarded as ultimate which does not identify them as one and the same thing.

Modern physical research has brought together a large number of previously isolated facts which, placed in order and logical sequence, have built up that comprehensive conception of electrical action known as the "Electron Theory."

The atom is no longer regarded as an absolute unit. It is now commonly believed that the hydrogen atom, for instance, is in reality an atomic system made up of a thousand or more electrons.

Spectrum analysis of metals shows that the hundreds of visible lines represent different rates of vibration acting within the unit atom. In other words, the atom consists of a thousand or more parts, each capable of independent action, these parts being called corpuscles or electrons.

Electrons are believed by some physicists to consist of ether. It is assumed that at rest electrons are spherical in shape; in motion their shape may be somewhat distorted, and at high velocities they probably take on the form of a disk. It has been demonstrated that each electron carries a definite negative

electric charge, measurable in conventional electromagnetic and electrostatic units.

In view of the belief that electrons are constituted of ether it is conceivable that in a free state they are present in metallic conductors, gases, and dielectrics, and, in a greater or less degree in all matter; their properties, however, being independent of the specific properties of the matter with which they may be associated.

A theory of electricity in order to be of service in experimental or practical applications of electrical energy should account for those manifestations which, for the want of better terms, are called positive and negative.

Even a moderate knowledge of physics carries one to a point where the electron theory is encountered, and this, opportunely at a stage where there is much need either of experimental proof or of a logical theory.

If a drop of water be divided into a hundred parts, each separate part will still exist as water. Should the division be carried to a point where one of these minute droplets is separated into its constituent parts of oxygen and hydrogen we would have then a molecule consisting of one atom of oxygen and two atoms of hydrogen. Further division would separate the oxygen and hydrogen atoms, and, as water, the drop would cease to exist. The electron theory presents an explanation of the constitution of the atom itself.

In accounting for the manifestation referred to as positive electricity, according to the electron theory, one might consider the circumstance of an isolated atom consisting of a number of electrons a trifle in excess of that necessary to give it proper atomic equilibrium. Should this atom come near to, or into contact with, another atom deficient in its quota of electrons, a transfer takes place which, in effect, establishes normal atomic equilibrium so far as these two atoms are concerned. It is assumed that the first atom would have a positive electric charge and the second a negative electric charge.

In the artificial generation of an electric current such as that due to chemical action, or to electromagnetic methods, there is brought about a sort of atomic storm with its accompanying stresses and transfers, its ever-contending and colliding elements and its readjustments which are taken advantage of and in various ways employed as energy.

The propagation of electric energy from one part of a metallic conductor to another is probably due to the constitution of the metal so employed. The atoms of the metallic element, the positive ions, being at liberty to revolve about a central point only, while the negative electrons are free to travel through the mass of the metal, electric current being due to the locomotion of these electrons; passed on, as it were, from atom to atom at great velocities.

Thus there is presented a provisional theory of the nature of electricity which, if not yet susceptible of lucid treatment, at least aids one in comprehending the causes of phenomena with which we have to deal.

Unfortunately there is not yet in vogue a terminology common to both

theory and practice to enable us in practical operations to avail of the benefits which might be expected to accompany a clear understanding of advanced theory.

As a link connecting the fore-going brief statement of the modern theory of electricity with what is to follow in succeeding chapters in regard to the practical application of electrical energy we have only to remember that electricity in locomotion constitutes current and magnetism, and that electricity in vibration constitutes light and other forms of electromagnetic radiation.

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CHAPTER I

ELECTRICITY AND MAGNETISM

UNITS AND SYMBOLS

Electrical action for practical purposes may be developed in several different ways. While electricity is the same, no matter what means are employed for its production, for the purpose of distinguishing between one means and another it is customary to refer to it under different classifications, such as Frictional Electricity, Thermal Electricity, Chemical Electricity, Magneto-electricity, etc.

Friction between a glass rod and a piece of silk produces a positive charge upon the surface of the glass, while the charge developed upon resinous bodies by friction with a piece of dry fur or flannel is negative. In each case an equal quantity of both charges is produced; that is, in the case of the glass and silk, the glass assumes a positive charge and the silk assumes a negative charge of equal quantity. In other words, one charge appears upon the body rubbed and an equal amount of the opposite charge appears upon the "rubber." The amount or quantity of charge developed upon either body is independent of the duration of friction, provided the entire surface of each body is brought into intimate contact with that of the other body. Further investigation along this line would show that electrified bodies bearing similar charges are mutually repellant, while electrified bodies bearing dissimilar charges are mutually attractive.

The Electrophorus, the Toepler-Holtz, and the Wimshurst machines are well-known generators, so called, of frictional electricity.

Thermal.—Thermal methods of producing electrical manifestations have nothing to do with practical telegraphy and shall not be considered here.

Chemical.—Chemical electricity has to do with the various forms of chemical batteries used in telegraphy for the purpose of producing the effect referred to as electric current.

Magneto- or Dynamo-electricity.—Magneto-electricity or dynamo-electricity is that derived by revolving by mechanical power, coils of insulated wire within the sphere of influence of magnets.

MAGNETISM

The natural magnet, or lodestone, is known as magnetite and has a chemical composition Fe_3O_4. This substance is found in various parts of Europe and in the United States. Its usual form is octahedron, although some fairly well-developed crystal specimens have been found.

If a piece of hard iron or steel be rubbed with a piece of lodestone, it will be found to have taken on magnetic properties.

A magnet sets up in the space immediately surrounding it a disturbance referred to as a magnetic field—a region pervaded by invisible lines of force. These lines act upon neighboring pieces of iron, iron filings, or other magnetic substances by what is commonly called magnetic induction. A magnet which retains its magnetism indefinitely and independently is called a permanent magnet, familiar forms of which are the bar magnet and the horseshoe magnet.

If a magnet be suspended by means of a thread or fiber and is free to turn in any direction, the presence of another magnet in close proximity to it will cause the first to set itself in a definite position relatively to the second magnet, and the imaginary line joining the poles of these magnets is called the magnetic axis. The greatest manifestation of magnetic force exerted by a magnet occurs at its ends or poles, and the two poles of a given magnet exhibit opposite characteristics which in practice are designated north and south, for reasons to be explained later.

Substances which are attracted by magnets when either pole is presented to them are called magnetic substances. Most common among such substances are iron, steel, nickel, cobalt, chromium and manganese. Such substances are paramagnetic.

If a piece of soft iron be magnetized by means of a permanent magnet it will lose practically all of its magnetic properties upon the withdrawal of the exciting magnet; any trace of magnetism which remains is termed residual magnetism. To magnetize a piece of steel requires longer time, but it is found that steel retains its magnetic properties a much greater length of time than does soft iron. One peculiarity of magnets is that their magnetism is materially impaired if they are subjected to knocks or jars.

RELATION BETWEEN ELECTRICITY AND MAGNETISM

The discovery was made in the year 1820 that a wire conveying an electric current exhibits characteristics practically identical with those peculiar to magnets. That is, it was found that the space immediately surrounding the wire is charged magnetically and so affects a magnetic needle that the latter tends to take up a position at right angles to the conducting wire. This discovery very quickly led to the development of electromagnets, now so extensively employed in nearly all methods of electric telegraphy.

CONDUCTORS AND INSULATORS

Conductors.—Conductors of electricity, so called, consist of substances which freely permit electrical action to progress from one portion of their mass to another. Insulators, or non-conductors, are substances which do not permit of unhampered progress of electrical action through them. The terms

conductor and insulator are relative distinctions, however, as it is well known that the best conductor available is far from being a perfect medium for the free progress of electrical action, and on the other hand it can be shown that the best insulator available is in a sense a conductor, as it is unable to completely stop the passage of the electric current. The best conductors are metals in the following order of conductivity:

Silver	Iron
Copper	Tin
Gold	Lead
Zinc	Mercury
Platinum	

Next in order of conductivity comes carbon, the acids, saline solutions, and water.

Insulators.—Insulators taken in order of their insulating qualities are:

Dry air	Silk
Glass	Wool
Ebonite	Porcelain
Paraffine	Oils
India rubber	Paper
Gutta percha	Marble

Potential Energy.—Mechanical energy is recognized in two forms: kinetic energy and potential energy.

When a body moves, it moves as a result of pressure having been exerted upon it by another body; the moving body then possesses kinetic energy—the energy of motion.

Potential energy may exist without producing motion, as in the case of a coiled steel spring or a suspended weight. One may, for instance, attempt to move a stone building by placing his shoulder against it, but there is no movement of the body acted upon, in which case there exists potential energy without any resultant kinetic energy.

Because of the similarity between the action of electricity in metallic conductors, and the flow of water in pipes, the hydraulic analogy has for many years been employed for the purpose of dealing with something tangible while explaining the behavior of electricity in conducting wires. The principles of hydraulics do not conflict with practical conceptions of electrical action based on the electron theory, for, when one understands that the universe is as full of what we term electricity as the ocean bed is of water, the use of the hydraulic analogy may be extended to meet modern requirements.

We know that water from the ocean is lifted up by evaporation and deposited in the hills in the form of snow and rain, thereafter to be conducted from a higher level back to the level of the sea by way of conducting channels which we call rivers. During its transfer from a higher to a lower level the energy

of the falling water may be availed of to turn water wheels and furnish power. Similarly, when the equilibrium of the electricity of the universe is disturbed by any one of the various means employed to set it in motion, the potential energy thus created may be availed of during the process of readjustment by presenting a convenient channel through which equilibrium may be restored. In practical operations the channel provided is known as an electric circuit.

Electric Potential.—Electric potential, or difference of potential is a difference of electric condition between two separated points along a conductor, or between two bodies, by virtue of which work is done as a result of the progress of electrical action from one point to the other, or from one body to the other as the case may be.

The electric potential of a body or a point refers to the potential of the body or the point as compared with the potential of the earth, which is assumed to be nil.

The property of producing a difference of electric potential is regarded as being due to a force referred to as electromotive force.

When it is stated that a certain battery or dynamo produces a definite electromotive force, it is meant that a certain definite difference of potential is thereby created between the terminals of the battery or the dynamo.

It is to be specially noted that electromotive force is not a mechanical force capable of setting a mass in motion, but rather a name given to the supposed force which causes a transfer of electrical action from one point to another in an electrical conductor.

An electromotive force may exist without producing electric current, in the same sense that mechanical potential energy may exist without producing kinetic energy.

The unit in which electromotive force is measured is the volt.

Resistance.—Resistance refers to that quality of a conductor by virtue of which it opposes the free flow of electricity.

The value of the resistance in ohms of a conductor depends upon the physical dimensions, temperature, and the kind of material of which the conductor is composed.

The resistance of a continuous wire of constant section and material is directly proportional to the length and inversely proportional to its cross-section.

The resistance of telegraph circuits, made up as they are through circuit-controlling contact points, consists of the resistance of the conductor and the resistance due to imperfect contacts.

The unit of resistance is the ohm.

Current.—A current of electricity is said to flow when two points in a conductor are at a difference of potential, in a manner analogous to the flow of water from a high to a lower level when a conduit or channel is provided for it; obviously a flow can take place only when a path is opened for the transfer. Hence, to have a current of electricity all that is required is an applied electro-

motive force and a closed conducting circuit joining the terminals of the source of e.m.f. Of course, as is brought out in a later chapter, a current may be induced in a circuit without direct application of an electromotive force; and it is true, also, that a current of electricity can be present in a circuit made up of earth, water, and of any conducting substance which may be so arranged that a continuous path is provided for it from a point of higher to a point of lower potential. But the strength of current present in any circuit varies directly as the electromotive force, and inversely as the resistance. The practical unit of current is the ampere.

UNITS AND SYMBOLS

A unit is the base of a system of measurement.

The statement of Ohm's law given in the latter part of the paragraph on Current, might be paraphrased in the following words: resistance equals electromotive force divided by current; electromotive force equals current multiplied by resistance, and current equals electromotive force divided by resistance.

It is evident, then, from the above that when any two of these factors are known the third may readily be calculated.

It is to be remembered, however, that:

resistance is stated in ohms,
e.m.f. is stated in volts, and
current is stated in amperes.

The symbols given herewith are those commonly employed in electrical calculations and while some of those listed are not encountered in everyday work it is desirable and convenient to list them all in one place.

Fundamental Units.

l,	Length, centimeter.
M,	Mass, gram.
T, *t*,	Time, seconds.

Derived, mechanical.

δ,	Dyne.
ε,	Ergs.
Ft. lb.,	Foot-pounds.
h.p.	Horse-power.
J	Joules' equivalent.

Derived, electrostatic.

q,	Quantity.
i,	Current.
e,	Potential difference.
r,	Resistance.
k,	Capacity.
sk,	Specific inductive capacity.

Derived, magnetic.

m,	Strength of pole.
$\mathcal{M}$,	Magnetic moment.
$\mathcal{I}$,	Intensity of magnetization.
$\mathcal{H}$,	Horizontal intensity of earth's magnetism.
$\mathcal{H}$,	Field intensity.
Φ,	Magnetic flux.
$\mathcal{B}$,	Magnetic flux density, or magnetic induction.
$\mathcal{H}$,	Magnetizing force.
$\mathcal{F}$,	Magnetomotive force.
$\mathcal{R}$,	Reluctance, magnetic resistance.
μ,	Magnetic permeability.
κ,	Magnetic susceptibility.
υ,	Reluctivity (specific magnetic resistance).

Derived, electromagnetic.

R,	Resistance, ohm.
Ω,	Resistance, megohm.
E,	Electromotive force, volt.
U,	Difference of potential, volt.
I,	Intensity of current, ampere.
Q,	Quantity of electricity, ampere-hour; coulomb.
C,	Capacity, farad.
W,	Electric energy, watt-hour; joule.
P,	Electric power, watt, kilowatt.
ρ,	Restivity (specific resistance), ohm-centimeter.
G,	Conductance, mho.
γ,	Conductivity (specific conductivity).
Y,	Admittance, mho.
Z,	Impedance, ohm.
X,	Reactance, ohm.
B,	Susceptance, mho.
L,	Inductance (coefficient of induction), henry.

Miscellaneous Symbols in General Use.

D,	Diameter.
r,	Radius.
θ,	Deflection of galvanometer needle.
π,	Circumference divided by diameter = 3.141592
$\backsim$,	Frequency, periodicity, cycles per second.
B. & S.	Brown & Sharpe wire gage.
B. W. G.	Birmingham wire gage.
$''$	Seconds, or inches.
$'$	Minutes, or feet.

$+$	Positive, or plus.
$-$	Negative, or minus.

Electrical units are expressed in terms of the centimeter, gram, second or c.g.s. system.

The centimeter is equal to 0.3937 in.

The gram is equal to 15.432 grains.

The second is the 1/86400 part of a mean solar day.

These units are generally referred to as the fundamental or absolute units. From these the derived or practical units of measurement have been determined, in order that the requirements of common practice may be met with standards which are immediately available.

The unit of force is that force which, acting for 1 second on a mass of 1 grm., gives the mass a velocity of 1 cm. per second. The unit is the dyne.

Work.—Work is the product of a force into the distance through which it acts. The unit is the erg, and equals the work done in pushing a mass through a distance of 1 cm. against a force of 1 dyne.

Power.—Power is the rate of working, and the unit is the watt $= 10^7$ ergs per second.

Horse-power.—Horse-power is the unit of power in common use and is equivalent to raising 33,000 lb. 1 ft. in 1 minute, or 550 ft.-lb. per second.

1 watt $= 10^7$ ergs per second.

1 horse-power $= 550 \times 1.356 \times 10^7$ ergs $= 746$ watts.

The Joule.—The joule (WJ) $= 10^7$ ergs, and is the work done, or heat generated, by a watt-second; or 1 ampere flowing for 1 second through a resistance of 1 ohm.

The Calorie.—The calorie is the amount of heat required to raise the temperature of 1 grm. of water 1° C.

Joules equivalent, J, is the amount of energy equal to a heat unit.

The electrostatic units derived from the fundamental c.g.s. units are based on the force exerted between two quantities of electricity, while the electromagnetic units so derived are based upon the force exerted between a current and a magnetic pole.

ELECTROSTATIC UNITS

So far no names have been assigned to the electrostatic units, but what is called the unit of quantity is that quantity of electricity which repels with a force of one dyne a similar and equal quantity of electricity placed at unit distance (1 cm.) in air.

Unit of Current.—Unit of current is that which conveys a current of unit quantity along a conductor in unit time (1 second).

Unit Difference of Potential, or Unit Electromotive Force.—Unit difference of potential, or electromotive force exists between two points when one erg

of work is required to pass a unit quantity of electricity from one point to the other.

Unit of Resistance.—Unit of resistance is possessed by that conductor through which unit current will pass under unit electromotive force at its ends.

Unit of Capacity.—Unit of capacity is that which, when charged by unit potential, will hold one unit of electricity; or that capacity which, when charged with one unit of electricity, has a unit difference of potential.

Specific Inductive Capacity.—Specific inductive capacity of a substance is the ratio between the capacity of a condenser having that substance as a dielectric to the capacity of the same condenser using dry air as the dielectric at 0° C., and a pressure of 76 cm.

MAGNETIC UNITS

Unit Strength of Pole.—Unit strength of pole (symbol m) is that which repels another similar and equal pole with unit force (1 dyne) when placed at unit distance (1 cm.) from it.

Magnetic Moment.—Magnetic moment (symbol $\mathcal{M}$) is the product of the strength of either pole into the distance between the two poles.

Intensity of Magnetization.—Intensity of magnetization (symbol $\mathcal{I}$) is the magnetic moment of a magnet divided by its volume.

Intensity of Magnetic Field.—Intensity of the magnetic field (symbol $\mathcal{H}$) is measured by the force the magnetic field exerts upon a unit magnetic pole, and therefore the unit is that intensity of field which acts on a unit pole with a unit force (1 dyne).

Magnetic Induction.—Magnetic induction (symbol $\mathcal{B}$) is the magnetic flux or the number of magnetic lines per unit area of cross-section of magnetized material, the area being at every point perpendicular to the direction of flux. It is equal to the magnetizing force or field intensity multiplied by the permeability; the unit is the gauss.

Magnetic Flux.—Magnetic flux (symbol Φ) is equal to the average field intensity multiplied by the area. Its unit is the maxwell.

Magnetizing Force.—Magnetizing force (symbol $\mathcal{H}$) per unit of length of a solenoid equals $4\pi NI$ divided by L; where N equals the number of turns of wire on the solenoid; L equals the length of the solenoid in centimeters, and I equals the current in absolute units.

Magnetomotive Force.—Magnetomotive force (symbol $\mathcal{F}$) is the total magnetizing force developed in a magnetic circuit by a coil; the unit is the gilbert.

Reluctance, or Magnetic Resistance.—Reluctance, or magnetic resistance (symbol $\mathcal{R}$) is the resistance offered to the magnetic flux by the material magnetized, and is the ratio of magnetomotive force to magnetic flux, that is, unit magnetomotive force will generate a unit of magnetic flux through unit reluctance; the unit is the oersted; *i.e.*, the reluctance offered by a cubic centimeter of vacuum.

Magnetic Permeability.—Magnetic permeability (symbol μ) is the ratio of the magnetic induction to the magnetizing force $\mathcal{H}$, that is $\frac{\mathcal{B}}{\mathcal{H}} = \mu$.

Magnetic Susceptibility.—Magnetic susceptibility (symbol κ) is the ratio of the intensity of magnetization to the magnetizing force, or $\kappa = \frac{\mathcal{J}}{\mathcal{H}}$.

Reluctivity, or Specific Magnetic Resistance.—Reluctivity, or specific magnetic resistance (symbol υ) is the reluctance per unit of length and of unit cross-section that a material offers to being magnetized.

ELECTROMAGNETIC UNITS

Resistance.—Resistance (symbol R) is that property of a material that opposes the flow of a current of electricity through it; and the unit is that resistance which with an electromotive force or pressure between its ends of 1 volt will permit the flow of a current of 1 ampere.

The practical unit of resistance is the ohm, and its value in c.g.s. units is 10^9. The standard unit is a column of pure mercury at a temperature of 0° C., of uniform cross-section, 106.3 cm. long and 14.4521 grm. weight. For convenience, when high resistances are being measured, such as the insulation of telegraph lines or cables, the prefix meg, meaning million, is used; thus is derived the megohm.

Electromotive Force.—Electromotive force (symbol E) is the electric pressure which forces the current through a resistance. Unit e.m.f. is that pressure which will force a unit current of 1 ampere through unit resistance. The unit is the volt, and the practical standard adopted by the London conference in 1908, is the Weston cell which has an e.m.f. of 1.01830 international volts at a temperature of 20° C. The value of the volt in c.g.s. units is 10^8.

Kilo-volt.—The kilo-volt = 1,000 volts, and the milli-volt = 1/1000 volt.

Current.—Current (symbol I) is the intensity of the electric current that flows through a circuit. A unit current will flow through a resistance of 1 ohm, with an e.m.f. of 1 volt between its ends. The unit is the ampere, and is practically represented by the current that will deposit silver electrolytically at the rate of 0.001118 grm. per second. Its value in c.g.s. units is 10^{-1}. The milliampere is 1/1000 ampere.

Quantity of Electricity.—The quantity of electricity (symbol Q) which passes through a given cross-section of an individual circuit in t seconds when a current of I amperes is flowing is equal to (It) units. The unit is therefore the ampere-second. Its name is the coulomb, and its value in c.g.s. units is 10^{-1}.

Capacity.—Capacity (symbol C) is the property of a material condenser for holding a charge of electricity. A condenser of unit capacity is one which will be charged to a potential of 1 volt by a quantity of 1 coulomb. The unit is the farad. Its c.g.s. value is 10^{-9}, and this being so much larger than ever obtains

in practical work, its millionth part, or the microfarad, is used as the practical unit, and its value in absolute units is 10^{-15}. Condensers used in telegraphy are usually made adjustable from 1/10 mfd. to 3 mfd.

Electric Energy.—Electric energy (symbol W) is represented by the work done in a circuit or conductor by a current flowing through it. The unit is the joule, its absolute value is 10^7 ergs, and it represents the work done by the flow for 1 second of unit current (1 ampere) through 1 ohm.

Electric Power.—Electric power (symbol P) is measured in watts and is represented by a current of 1 ampere under a pressure of 1 volt or 1 joule per second. The watt = 10^7 absolute units, and 746 watts = 1 h.p. In electric lighting and power operations the unit kilowatt (1,000 watts) is generally employed to avoid the use of large numbers.

Resistivity.—Resistivity (symbol ρ) is the specific resistance of a substance, and is the resistance in ohms of a centimeter cube of the material to a flow of current between opposite faces.

Conductance.—Conductance (symbol G) is the property of a metal or substance by which it conducts an electric current, and equals the reciprocal of its resistance. The unit proposed for conductance is the mho, but it has not come into extensive use as yet.

Conductivity.—Conductivity (symbol γ) is the specific conductance of a material, and is therefore the reciprocal of its resistivity. It is often expressed in comparison with the conductivity of some metal such as silver or copper and is then stated as a percentage.

Inductance.—Inductance (symbol L) or coefficient of self-inductance of a current is that coefficient by which the time rate of change of the current in the circuit must be multiplied in order to give the e.m.f. of self-induction in the circuit. The practical unit is the henry, which equals 10^9 absolute units, and exists in a circuit when a current varying 1 ampere per second produces a volt of electromotive force in that circuit. The millihenry is equal to 1/1000 henry.

In the operation of telegraph lines the factor of inductance in open air lines is almost negligible, but the inductance of signaling instruments employed in terminal equipment is of considerable consequence; indeed in some cases the receiving end inductance is a criterion of speed.

Practical methods of testing the inductance of coils and magnets will be taken up later.

CHAPTER II

PRIMARY BATTERIES

Although at the present time dynamo machinery is employed to furnish most of the electric current used in telegraph operation, the fact that nearly half a million dollars are paid annualy for gravity-battery materials would indicate that primary batteries are still used extensively as sources of power.

It must be admitted that the primary batteries in use to-day are practically the same in design and construction as those employed in the operation of the early telegraph systems. Little or no advance in this regard has been made. Certain objections to their use, probably considered inherent, have never been satisfactorily overcome. The objectionable features are: high internal resistance, loose and easily deranged assembly of elements, poorly designed terminal connections, high cost of supervision, and high cost of constituent materials.

The function of a battery is to maintain in a conducting circuit, an electric current by means of chemical action set up between two dissimilar metals conveniently immersed in an electrolyte which possesses a chemical affinity for one of these metals. The activity of this action in a given type of cell determines the voltage or electromotive force of the battery. The voltage of a cell is in great part dependent upon the particular metals and electrolytes employed in its assembly. One of the elements is termed the anode and the other the cathode. In the gravity cell, for instance, the zinc is the anode and the copper the cathode. In each case the former is the positive plate and the latter the negative plate. The atoms which gather at each plate are called anions and cathions respectively.

For telegraph working it is necessary to have a type of battery which will not quickly lose its strength on closed circuit. Sounder circuits and main-line circuits are frequently closed several minutes and sometimes for hours at a time, so that a battery, such as the well-known dry-cell, which "runs down" quickly when short circuited or when connected in circuits having low resistances, would not be suitable for closed-circuit telegraph work.

Batteries, then, are classified as open-circuit types or closed-circuit types. The LeClanche and the dry-cell are examples of the former, while the gravity, Edison-Lalande and the Fuller cells are examples of the latter. Again, battery cells are classified as single-fluid or double-fluid types. The Le-Clanche and Lalande are single-fluid cells while the gravity and Fuller are double-fluid cells.

Before going into a detailed description of the action and construction of the various types of battery used in practice it may be well for the purpose of reference to give some tabulated data in regard to the general subject.

CHEMICALS COMMONLY EMPLOYED AND THEIR SYMBOLS

	Symbol
Hydrogen	H
Potassium	K
Copper (cupric)	Cu
Carbon	C
Platinum	Pt
Ammonium chloride (Sal-ammoniac)	NH_4Cl
Bichromate of potassium	$K_2Cr_2O_7$
Bichromate of soda	$Na_2Cr_2O_7$
Cadmium sulphate	$CdSO_4$
Chromic acid	CrO_3
Copper oxide	CuO
Caustic potash or potassium hydrate	KOH
Copper sulphate (blue-vitriol)	$CuSO_4$
Hydrochloric acid	HCl
Lead oxide	PbO
Lead peroxide	PbO_2
Mercurous sulphate	Hg_2SO_4
Manganese dioxide	MnO
Nitric acid	HNO_3
Sulphuric acid	H_2SO_4
Silver chloride	$AgCl$
Sodium chloride	$NaCl$
Zinc chloride	$ZnCl_2$
Zinc sulphate	$ZnSO_4$
Zinc sulphate (white-vitriol)	$ZnSO_4$

TYPES OF CELL

Name	Negative pole	Positive pole	Electrolyte	Depolarizer	E. M. F. volts	Internal resistance
Gravity	Zinc	Copper	Zinc sulphate	Copper sulphate solution.	1.07	2.5 ohms
LeClanche	Zinc	Carbon	Ammonium chloride.	Manganese dioxide.	0.75	1.5 ohm
Fuller	Zinc	Carbon	Sulphuric acid	Bichromate of potassium.	2	0.5 ohm
Edison-Lalande	Zinc	Copper	Caustic potash	Cupric oxide	0.8	0.050 ohm

The Voltaic Cell.—A simple voltaic cell may be assembled as shown in Fig. 1, which represents a zinc and a copper plate immersed in a sulphuric acid solution which is contained in a glass jar. If the exposed terminals of the copper and zinc plates are joined by a connecting wire, the acid attacks the zinc, the latter being gradually dissolved forms hydrogen gas which escapes in minute bubbles. The chemical action thus set up results in a continuous

current from the zinc (positive) plate to the copper (negative) plate through the liquid (electrolyte). The chemical transfer going on carries hydrogen bubbles to the surface of the copper electrode; from there the path or circuit is metallic—that is, through the connecting wire back to the zinc terminal.

It may here be observed that, within the battery jar the current is from zinc (positive) to copper (negative) and in the external connecting circuit the current is from copper to zinc.

Inasmuch as the function of the cathode or negative element is, mainly, to serve as a conductor of the current from the electrolyte, although somewhat paradoxical, it is customary to refer to the cathode as the positive terminal of the cell. When the external circuit is closed or "completed" an electric current flows and the zinc is wasted away. The consumption of the zinc plate furnishes the energy which causes the current to flow through the electrolyte and the connecting circuit. The cell might be likened to a chemical furnace in which the zinc is the fuel.

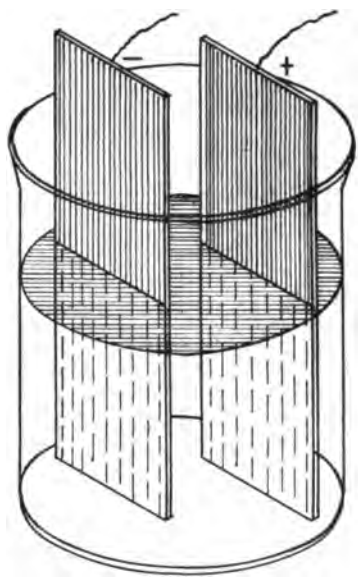


FIG. 1.—Simple voltaic cell.

The exact nature of the chemical action which takes place within the voltaic cell might be described as follows: The affinity of the acid for the positive plate (zinc) produces a difference of potential between the two terminals of the cell. In the simple cell employing sulphuric acid as the electrolyte; we have first to consider the constitution of the acid. Sulphuric acid, H_2SO_4, consists of a group of atoms, 2 of hydrogen, 1 of sulphur, and 4 of oxygen. The oxygen and sulphur conbination has a decided affinity for the zinc, and when the copper and zinc plates are joined by a connecting wire, attacks the zinc plate forming zinc sulphate, $ZnSO_4$, which is dissolved in the water. There are, then, two parts of hydrogen gas set free for every portion of the SO_4 part of the sulphuric acid which unites with the zinc. Thus when the hydrogen is liberated the zinc takes its place. Zinc sulphate and hydrogen are produced by sulphuric acid and zinc. The equation representing the action which takes place is expressed in the following manner:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

Action continues only as long as the external circuit is closed, that is, when the positive element employed consists of chemically pure zinc. When, however, commercial zinc is used, which in many instances contains impurities

such as carbon, tin, arsenic, lead, iron, etc., there is a local action going on which results in the consumption of zinc without the desired production of useful current. For the purpose of overcoming this local action it is customary to amalgamate the zinc elements used in chemical batteries. The process of amalgamation consists of cleaning the surface of the zinc by immersing it in an acid and then rubbing upon the zinc a coating of mercury which unites with the zinc and forms an amalgam paste. The foreign matter contained in the zinc does not dissolve in the mercury but floats to the surface and is carried off by the constantly forming hydrogen bubbles. The zinc associated with the mercury dissolves in the acid solution and the mercury coating continually uniting with fresh portions of zinc results in a clean bright surface of zinc being at all times presented to the attacking acid.

As before stated, the hydrogen set free is carried away in the form of minute bubbles, and while most of these bubbles reach the surface of the liquid there releasing their charge, an increasing number of them gather upon the surface of the copper electrode, the longer the cell is used. Now, as these hydrogen bubbles are electropositive in practically the same sense as is the zinc element itself, the copper element by virtue of this accumulation of hydrogen bubbles upon its surface, is converted into a positive element, at least that would be the result if the action were permitted to continue indefinitely. This action is called Polarization.

There are several well-known ways of overcoming this tendency to polarize. Theoretically, the desired end might be accomplished simply by brushing the bubbles off the cathode, but in practice it is desirable to secure the same result automatically.

It is customary to employ as a constituent of the cell a substance with which the hydrogen gas will readily combine. Such substances are called Depolarizers. Depolarizers may be either solid or liquid. When solid, the usual method is to shield the cathode with a substance in porous form as in the Leclanche and Fuller types. When a liquid depolarizer is used, if its specific gravity be less than that of the electrolyte, they will be kept separate by placing the lighter on top of the heavier liquid as in the gravity cell.

There are several depolarizers which may be used with good results, namely, oxide of copper, peroxide of manganese, nitric acid, permanganate of potash, chromic acid, bromin in caustic soda, and sulphate of copper solution.

The Gravity Cell.—In the gravity cell the depolarizer used is sulphate of copper (solution). Fig. 2 shows the usual type of gravity cell used in telegraph and telephone work. In the bottom of the glass containing-jar is placed a "star" of copper sheet, attached to which is a well-insulated wire extending out of the top of the jar for the purpose of making terminal connection. A portion of about 3 lb. of blue-vitriol (sulphate of copper) is placed in the bottom of the jar, being well distributed around the copper element and almost covering it. The vitriol crystals used should be broken up so that none of those

placed in the jar are larger than a walnut. The fine particles or dust of vitriol should not be used. The zinc which is provided with a hanger is then suspended from the upper edge of the jar and the jar filled to within a half inch or so of the top with pure soft water. Clean rain water, if available, is the best for the purpose. Impure or hard water prevents proper action of the chemicals and should not be used. When a cell is first set up it is customary to hasten its action by "short circuiting" the copper and zinc terminals by means of a short piece of wire. In a short time zinc sulphate is formed around the zinc, and a copper sulphate solution forms around the copper, the two fluids being separated because of their different specific gravities. A cell in good condition shows a fairly clear line of demarcation between the two solutions. The zinc sulphate appears to float on the top of the denser copper solution beneath. If the circuit connecting the terminals of the cell, or of the battery of which the cell forms a part, is left open and the cell not called upon to do enough work to prevent mixing of the solutions, the copper sulphate gradually comes into contact with the zinc and is decomposed, forming cupros oxide (CuO) which completely covers and adheres to the zinc. In appearance this deposit resembles black mud. Crystallization of the zinc sulphate is evidenced by the formation of salt-like crystals which creep over the upper edges of the jar and down its sides, and unless periodically cleaned away, in a comparatively short time make a disagreeable mess on battery shelves. To prevent the creeping of salts over the tops of jars a mineral oil of high viscosity is sometimes applied by pouring it over the top of the solution to a depth of 1/16 to 1/8 of an inch.

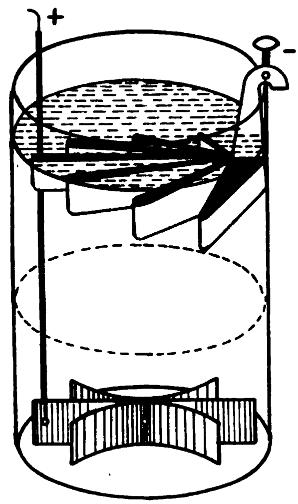


FIG. 2.—Gravity cell.

The specific gravity (sp. gr.) of water has been assigned the value of 1.00, and the density or weight of all other liquids is measured in comparison therewith. Sulphuric acid has a sp. gr. of 1.84, mercury 13.58, etc. For the practical measurement of the specific gravity of a liquid an instrument called a hydrometer is used (see Fig. 3). This instrument consists of a hollow sealed glass tube or float, weighted at its lower extremity with lead shot, the stem of the float being provided with a graduated scale. When a hydrometer is allowed to float freely in a liquid, the division of the scale on a level with the surface of the liquid indicates the specific gravity of the liquid so tested. There are two or three different makes of scale, but the one generally used is known as the Baume scale which registers divisions from 0 to 45. When a gravity cell is at its best the scale will sink to 20°. Should a test show that the density of the solution is below 5° or above 25° the cell is not in good condition. It is when

the density of the zinc solution rises above 25° that the crystallization of the zinc sulphate is most active. Obviously, the remedy is, as indicated above, to short circuit the cell until the chemical action has had an opportunity to restore normal conditions; that is, when the impoverished condition of the cell is the result of having been left on "open circuit" for an unreasonable length of time.

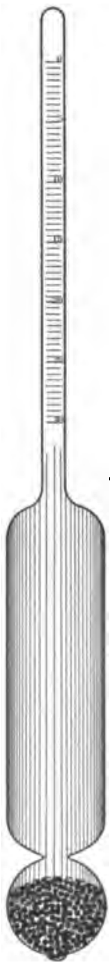


FIG. 3. Hydrometer.

In the installation and maintenance of gravity batteries there are a few points of sufficient practical importance to warrant consideration here.

It is of considerable benefit to have jars well cleaned and dried before being used in setting up cells.

The insulated conductor leading from the copper should in each case be securely riveted, making solid contact.

It is not good practice to attempt to renew impoverished cells by occasionally dropping in a few crystals of bluestone.

Cells in service should frequently be tested with the hydrometer. In case the specific gravity rises above 25°, additional soft water should be added. To do this, some of the zinc solution may be removed by means of a rubber-tube syphon. The rubber tube used for this purpose should be kept clean.

Battery shelves should be kept scrupulously clean.

If the insulating material surrounding the wire leading from the copper becomes cracked, the wire should be replaced with one properly insulated.

Cells should be renewed when the original charge of blue-vitriol is nearly exhausted or when the two solutions have become too intimately merged.

Gravity cells should be disturbed as little as possible.

When a cell is for any reason taken down and there is enough of the zinc remaining to warrant using it again, it should be cleaned off while wet as the deposits harden very quickly and later are difficult to remove.

Coppers may be cleaned by laying the plates separately on a hard surface and hammering off the deposits.

The temperature of a battery room should not be permitted to get below 60° F.

The rapidity with which the materials of a cell are consumed depends upon the amount of work done by it—upon the quantity of electricity per unit of time that it is required to supply. The consumption and deposition of the materials used in gravity cells per ampere-hour, in fractions of an avoirdupois pound, and from which the cost of producing a given current may be ascer-

tained, theoretically, when the price of the materials is known,[1] may be calculated from the following table:

Material	Atomic weight	Pounds, per ampere-hour
Zinc consumed	64.9	0.0026749
Sulphate of copper consumed	249.5	0.0102810
Copper deposited	63.0	0.0025949

In the computation the copper deposited is a credit.

The electrochemical equivalent of zinc is here taken as 0.00033696 grm. per ampere-second according to the determinations of Rayleigh and Kohlrausch.

The average life of a cell used for furnishing current for "local" circuits, that is, sounders and multiplex and repeator locals, is from five to eight weeks, a main-line battery supplying one or more main-line wires two months, and a duplex or quadruplex battery about six months. These estimates presuppose intelligent and careful supervision of the batteries so employed. A space interval of at least 3/4 in. should be maintained between individual cells on a shelf. It is extremely important to have all connections between cells and of battery terminals tight and secure.

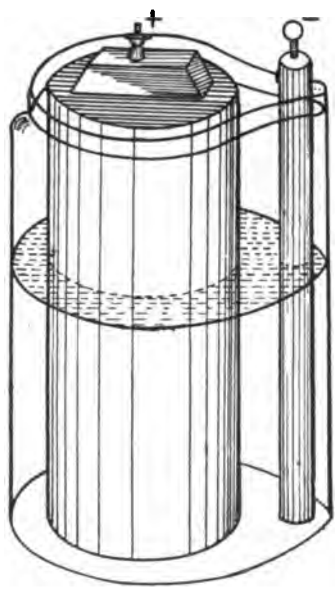


FIG. 4.—Leclanche cell.

The Leclanche Cell.—The Leclanche cell is not used in the operation of telegraph lines but it has an extensive general employment in operating signaling bells, telephones, etc., and for that reason its action and assembly should be understood. A familiar form of this type of battery is shown in Fig. 4. The cell consists of a glass containing-jar about half the size of that used for the gravity cell, a porous-cup containing a plate or rod of carbon (the inactive element) and a zinc pencil (the positive element). The exciting liquid is a salammoniac solution in which the zinc dissolves, forming a double chloride of zinc and ammonia, while at the same time ammonia gas and hydrogen are liberated at the carbon plate contained in the porous-cup. The depolarizer is black binoxide of manganese, small pieces of which are mixed with powdered carbon and the mixture thus formed packed around the carbon rod within the

[1] F. L. Pope, "The Electric Telegraph," p. 74.

2

porous-cup. As a depolarizing agent the oxide of manganese slowly gives up oxygen as required. The porous-cup does not prevent the passage of current, but protects the zinc from the action of the oxide.

The constituent materials of the porous-cup are: feldspar, 8 parts; ball clay, 6 parts; kaolin, 9 parts; and 2 parts quartz—the latter is added for the purpose of giving the mixture the required mechanical strength. The mass is then pulverized, mixed with water and boiled for 24 hours, after which it is moulded into cups of the desired dimensions and baked in a dry kiln at a temperature of 1,800° F., for a period of 24 hours.

If left on short circuit or worked hard, it is impossible to entirely prevent polarization, but after showing signs of polarization, if the cell is left on open circuit for a short time it rapidly recuperates. It is best not to use a salammoniac solution too strong, as crystals will gather on the zinc and thus reduce the surface of the zinc exposed to the solution. On the other hand, if the solution is too weak, chloride of zinc will form on the zinc element. Either of these conditions considerably increases the internal resistance of the cell. As in the gravity cell, soft clean water should be used in forming the solution. About 6 oz. of salammoniac is sufficient per cell, and water should be added until the jar is filled to within 3/4 in. of the top of the jar. The solution should be stirred until the salammoniac has dissolved. The upper part of the carbon cylinder or porous-cup should be kept clean and dry in order to prevent leakage of current between the poles. To renew the cell, all that is necessary is to clean or renew the zinc element and pour some fresh solution into the jar. The carbon is the negative element of the cell and the positive pole; the zinc is the positive element and the negative pole.

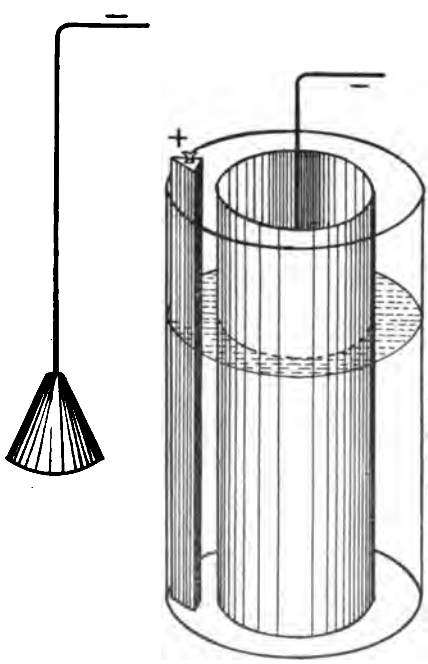


FIG. 5.—Fuller cell.

The Fuller Cell.—There are several forms of this type of battery, but the action of and the assembly of the various forms is practically the same. This cell is sometimes referred to as the bichromate cell because of the employment of bichromate of potash together with a dilute sulphuric acid solution as the electrolyte. The bichromate chemically unites with the hydrogen and prevents polarization. A common type of Fuller cell is shown in Fig. 5.

A well-amalgamated block of zinc is placed in a porous-cup which is nearly filled with a dilute solution of sulphuric acid. The cup is placed in the center of a glass jar about the size of a Standard gravity jar. A carbon plate of comparatively large section is placed in the jar at one side of, or completely surrounding the porous-cup. The containing vessel is then filled to within 1/2 in. of the top with a solution of potassium bichromate. It is customary to keep a spoonful or so of mercury in the bottom of the porous-cup so that the amalgamation of the zinc contained therein may be continuously renewed.

The bichromate solution (electropoin) is made up of 1 part sulphuric acid, 3 parts bichromate of potash, and 9 parts water. The bichromate should be dissolved in warm water and when cool the required amount of sulphuric acid should be slowly added. The reverse process should never be attempted; that is, the bichromate solution should not be poured into the sulphuric acid, as excessive heat and distressing fumes will thereby be generated. When first set up the solution is of a light brown color and as it ages, gradually turns darker.

As the internal resistance of this cell is but 0.5 ohm and its e.m.f. 2 volts, it is an unusually powerful source of current and it has many uses, especially when it can be employed where intelligent handling may be availed of. It is always inadvisable to allow any but careful attendants to handle destructive acids.

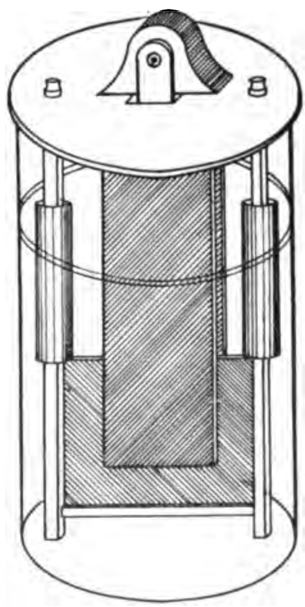


FIG. 6.—Edison-Lalande cell.

The Edison-Lalande Cell.—This cell is capable of yielding a large current—as much as 30 amperes on short circuit, due to its low internal resistance and relatively high e.m.f., 0.75 volt.

The cell is made up of zinc and copper oxide in a solution of caustic potash. As usually constructed the plates are hung side by side from the cover of the jar. The copper oxide is plated with a film of copper for the purpose of reducing the initial resistance of the cell, and is held in a frame suspended from the cover. To prevent the inevitable creeping of salts, a film of oil is poured on top of the solution. When the solution is being mixed the caustic potash should not be placed in the cell and left to dissolve as it is very likely to solidify at the bottom of the jar. The solution should be stirred until all of the potash is dissolved. As the solution used in this battery will burn the skin and clothing, great care should be exercised when stirring, to avoid splashing. In renewing the Lalande cell a new solution should be set up at the time the zincs and oxides are renewed. The solution should always reach to the lower colored line in the jar, after it has cooled down; usually it

is found necessary to add a little water to bring it up to this line after the cooling process. Fig. 6 shows a view of an assembled Edison-Lalande cell.

The Dry Cell.—Generally speaking, dry cells are modifications of the sal-ammoniac cell, in which the water is replaced by one of the various gelatinous substances available for the purpose. The Gassner cell, one of the original dry-cell products, embodied a paste made of 1 part oxide of zinc, 1 part sal-ammoniac, 3 parts plaster, 1 part zinc chloride, and 2 parts water, all by weight. Fig. 7 shows a typical construction of dry cell as at present manufactured in this country.

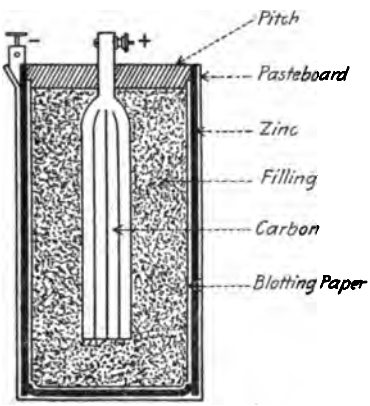


FIG. 7.—Dry cell.

In making up dry cells a zinc cylinder is lined on the inside with blotting paper or an absorbent cardboard. The exciting fluid is poured into the cylinder and left for a period of 15 minutes to soak thoroughly. The electrolyte is then poured out and the cylinder inverted so that the surplus liquid may drain off. The carbon rod is then inserted and the space between it and the sides of the absorbent paper is filled with the depolarizer which usually consists of black oxide of manganese and granulated carbon, this mixture is moistened with the electrolyte before placing it in the shell. On the surface a layer of dry sand is placed and on the top of this hot pitch is poured and allowed to harden. The function of the depolarizer is to furnish a supply of oxygen required to keep up combustion. After the cell has been short circuited for a brief period or worked hard for a considerable length of time the oxygen in the depolarizer is consumed, the latter gradually hardens and the pores close up. When the oxygen is gone the cell ceases to

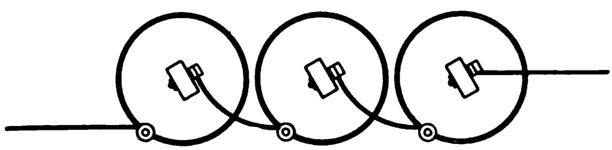


FIG. 8.—Arrangement of dry cells on shelf.

be of value as a generator of electricity. The electrical output of a dry cell, as well as its length of life for a stated output is, in large measure, dependent upon the dimensions of the exposed areas of the zinc and carbon.

An important consideration in the manufacture of dry cells is the thickness of the zinc strip used in forming the shell. The plate employed for the purpose ranges in thickness from 0.014 in. to 0.025 in. The former will be eaten through much moré quickly than the thicker plates and the result is that the life of the

cell is considerably shortened on account of the moisture oozing out and soaking into the cardboard casing. If two adjacent cells are thus affected and the wet sides come into contact an effectual short circuit is established which may destroy the efficiency of an entire battery. One method of overcoming this is to use pasteboard covers which have been boiled in a mixture half beeswax and half paraffine. It is good practice in arranging dry-cell batteries on shelves to set the cells a half inch or so apart and in the manner shown in Fig. 8 in order to prevent any possibility of short circuit.

Standard Cells.—In determining the absolute value of a standard e.m.f., instead of depending upon the accuracy of a measuring instrument to register values, a standard cell constructed from definite specifications is used.

Three types of cell which have been used for the purpose are the Clark, the Carhart-Clark, and the Weston cell.

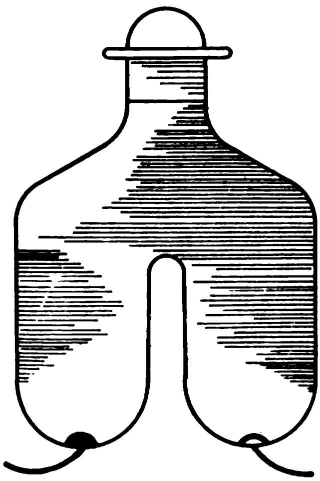


FIG. 9*a*.—Clark standard cell.

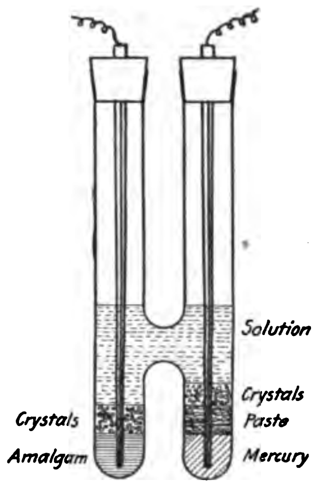


FIG. 9*b*.—Weston standard cell.

The Electrical Congress held in Chicago in 1893 adopted the Clark cell as the international standard of e.m.f. In this cell the positive element is mercury, the negative amalgamated zinc, and the electrolytes saturated solutions of sulphate of zinc and mercurous sulpate. At a temperature of 15° C., the e.m.f. is 1.434 international volts.

The Carhart-Clark Cell.—This cell embodies the same elements as the Clark, but the solution of zinc sulphate is saturated at 0° C., the e.m.f. being 1.440 volts.

Weston Cadmium Cell.—The elements of this standard cell are cadmium and mercury and the electrolytes sulphates of cadmium and mercury.

On January 1, 1911, the Bureau of Standards at Washington adopted a new value for the electromotive force of the Weston cell, namely, E =

1.01830 international volts at 20° C. This change was made pursuant to official definitions of values adopted by the International Electrical Congress held in London in 1908. As compared with the standard e.m.f. previously employed, the change is equivalent to an increase of about 0.08 of 1 per cent. in the value of the international volt.

The usual form of construction of the glass-containing vessel of the Clark standard cell is shown in Fig. 9-*a*, and that of the newer type of Weston cell in Fig. 9-*b*.

This is called the "H" form of cell. This type is quite easily filled, permitting the contents of each leg rapidly to take on the normal temperature of the bath. A 2-mm. platinum wire is sealed in each leg, the tips being flattened flush with the glass, making good contact with the mercury or amalgams. The mercury, amalgam and paste each have a depth of from 10 to 15 mm. Some crystals are placed above the paste, and on top of the amalgam a layer of crystals is laid to a depth of 10 mm. The cell is filled to the top of the cross tube with the saturated solution. The Weston cell has a temperature coefficient of about one-thirtieth of that of the Clark cell. This, however, is not of great importance as the cells are maintained in a bath the temperature of which is automatically controlled. The electromotive force of these standard cells is quite constant, but decreases slightly with age. Fifteen cells in use in the laboratories of the Bureau of Standards have on the average decreased one-ten thousandth of a volt in four years.

CHAPTER III

DYNAMOS, MOTORS, MOTOR-GENERATORS, DYNAMOTORS, VOLTAGE AND CURRENT REGULATORS

Electro-mechanical Generators of Electricity.—These at the present time are used quite extensively to furnish current for the operation of telegraph lines, also for the operation of terminal apparatus including main-line and local instruments.

In some instances current furnished by commercial power companies is used directly, being supplied by one or more pairs of wires from the power station to the telegraph office; there the current is distributed to the various circuits by means of switching systems.

In general, however, the operation of telegraph circuits requires the employment of different voltages, ranging about as follows: 40 volts, 85 volts, 125 volts, 200 volts, and 375 volts. Further, it is necessary that at least the two last named voltages be available in both negative and positive polarities.

Regardless of considerations of economy, the usual practice is to generate on the ground (in the telegraph office) the different values of potential required in each individual installation. There are two ways in which the desired end may be accomplished. One way is to set up a number of dynamos capable of generating like values of e.m.f., and to connect a sufficient number of them in series to produce an aggregate voltage equal to the maximum required. If, then, the units are arranged in multiples of 40 volts, potentials of the following specified values may be tapped off: 40 volts, 80 volts, 120 volts, 160 volts, 200 volts, 240 volts, 280 volts, 320 volts, 360 volts, and 400 volts. That is, in order to provide voltages ranging from 40 to 400 in multiples of 40 volts, ten dynamos are required. It is obvious that a series of machines so connected would all be of one polarity, either negative or positive, and that a duplicate set of machines having identical ranges of voltage are required to supply the opposite polarity. Where this method is employed it is customary to have in readiness a third group of machines as reserve and so connected through switches that either polarity may be availed of.

Another method is to make use of generators having different individual voltage outputs. That is, one dynamo for each polarity of each voltage required.

In either case an external source of power is required to drive the dynamos, and the customary method of driving these machines is through the medium of electric motors mechanically connected to the rotating elements of the

dynamos. The chief advantage of this arrangement is that any available commercial voltage whether it be direct current or alternating current, or whether the potential is 110 volts, 220 volts or 500 volts, may be employed to operate the motors and still the e.m.f. of each dynamo driven by its respective motor will accord with its rated output. One dynamo delivering 40 volts, another 85 volts, another 200 volts, and so on.

What follows in regard to the construction of and operation of dynamos includes only such detail as seems necessary to adequately present the subject, from a telegraph standpoint.

In a dynamo an e.m.f. is induced in wires caused to move through the magnetic field near the poles of a magnet. The magnetic field is the space about the magnet within which a piece of iron would be attracted to or repelled from it. The direction and strength of the magnetic force causing this attraction or repulsion is determined, and a certain unit value selected; called a line of force; by which the intensity of the magnetic field can be measured. The total number of lines of force issuing from the magnet is called its magnetic flux.

The value of the e.m.f. induced in the wires referred to depends upon the number of lines of force they cut in a certain time, that is, upon the "rate" at which the lines of force are cut. If the wires are simply held in the magnetic field, no e.m.f. is generated. Either one must move with respect to the other if an e.m.f. is to be produced in the wires. If the wires move through the field in one direction, the e.m.f. produced will cause the current to flow in a direction the reverse of that resulting from moving the wires in the opposite direction. Also, the direction of the current in the wire moving under a north pole is opposite to that of the current in the wire moving under the south pole of a magnet.

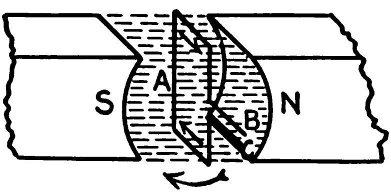


FIG. 10.—Dynamo field-magnet poles.

Figure 10 shows the poles of a pair of electromagnets, one marked *N* (north) the other *S* (south). The dotted lines represent lines of force (shown thus for the purpose of clearness) streaming across the gap in a direction from north pole to south pole. The armature is represented as a single loop of wire *A*, with its ends *B* and *C* brought out at one side. If the loop is revolved in the direction indicated by the curved arrow it passes through the lines of force and an electric current is induced in the loop flowing in the direction shown by the straight arrows. As the coil is moved through a complete revolution it is evident that each side of it will come within the influence first of one pole and then of the other thus reversing the direction of the current in the loop twice during each complete revolution. The result is that alternating current is produced in the armature coil, that is, current which alternates

in polarity from positive to negative and negative to positive as indicated above.

If an alternating current is desired the terminals of the armature coil (or coils) are connected with "collector" rings which are mounted on one end of the armature shaft and separately insulated from it, the current being taken off by means of carbon brushes, one in contact with each collector ring and mounted in stationary brush holders to which the wires of any external circuit may be connected.

When a unidirectional or direct current is required, as is usual in telegraphy, it is necessary to use a commutator in order to take from one of the brushes a constant positive current and from the other a constant negative current.

Figure 11 illustrates the end view of a commutator having a number of insulated segments to which the ends of individual armature coils may be attached. In the figure one coil only is shown. The brushes which serve to lead the current away from the dynamo to any desired external circuit are shown in position. The commutator is built in the form of a sleeve or ring and mounted on one end of the armature shaft. The commutator *C* is built up of strips of copper, forming segments *S*, *S*, all insulated from each other, the entire commutator being insulated from the shaft upon which it is rigidly mounted. Remembering that the coil *W* is mounted on the armature and that it is revolved between the poles of an electromagnet, if we consider that the coil terminal *E* is positive at the instant shown, a positive current may be taken from brush *B*. But, as the coil is moved around one-half revolution, the current in it reverses and the terminal *F* being then in contact with brush *B* delivers at that point a positive current. This must be so as the brushes are stationary, and the pole pieces of the electromagnets are stationary and when the terminal *F* comes into contact with brush *B* it must necessarily be in the same position in the magnetic field as terminal *E* was when in contact with brush *B*.

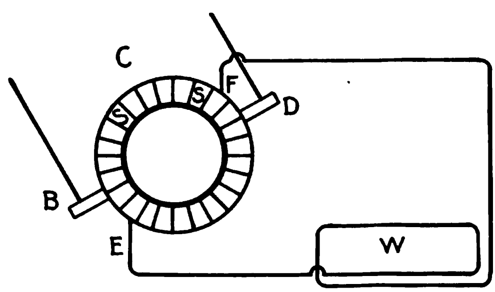


FIG. 11.—End view of commutator, showing one armature coil.

Dynamo Fields.—In the various types of dynamos manufactured at the present time, three varieties of field-magnet iron are used, namely, cast-iron, cast-steel, and sheet-steel. It has been determined that a greater number of lines of force can be produced with a certain magnetizing force in a given section of sheet-steel than in similar sections of cast-steel or cast-iron. From the standpoint of magnetic permeability, mild steel is next in order and then

follows cast-iron. The coils of insulated wire wound around the pole pieces of a dynamo constitute the field winding. The purpose of these coils is to conduct a current of electricity through them in order to inductively magnetize the poles. The amount of magnetism generated is dependent upon the number of turns of wire in the field coils and upon the volume of current which is passed through these coils.

As was brought out under the heading of current in Chapter I, the practical unit of current is the ampere. Although the subject of electromagnets will be taken up in detail in a later chapter, it may here be stated that the unit of magnetizing force is the ampere-turn, which signifies that 1 ampere of current is flowing in 1 turn of wire wound around the core of a magnet. The total magnetizing force is determined by multiplying the number of turns of wire wound around the core of a magnet by the number of amperes flowing in the circuit thus formed. An equal number of lines of force are generated by 1 ampere flowing in 50 turns as by 50 amperes flowing in 1 turn, or as 2 amperes in 25 turns. The product of the turns and the amperes determines the total magnetism developed. The factors may have any value provided the product is equal; or, $T=t\times I$. Where T represents the ampere turns, t the number of turns of wire and I the current in amperes, flowing.

Field Excitation of Dynamos.—The field magnets of dynamos may be energized either by current from some external source or by current taken from the commutator brushes of the machine itself. When an external source of current is used, it is immaterial, theoretically, whether it is a primary battery, storage battery, or an independent dynamo, provided the current supplied is unidirectional.

In the smaller makes of dynamos, such as those used in furnishing telegraph currents, the self-excited dynamo is the type generally used. Self-excited generators may be either series wound, shunt wound, or compound wound.

Series-wound generators deliver a voltage which increases with the load.

Shunt-wound generators deliver approximately constant voltage.

Compound-wound generators deliver constant voltage.

In series-wound closed-coil-armature generators the entire field winding is in series with the armature, and consequently the field coils carry the entire current generated.

Figure 12 in simple lines shows the wiring of a bi-polar series-wound dynamo.

In a shunt-wound dynamo the field winding is connected to the brushes in the manner illustrated in Fig. 13. A field regulating rheostat is inserted as shown.

A compound-wound generator as shown in Fig. 14 is provided with a shunt field winding connected to the brushes in series with a rheostat and

with a second winding connected in series with the armature. At no-load the shunt winding excites the machine to normal voltage. When the external circuit or load is applied, the field excitation is strengthened because of the current then allowed to flow through the series winding. For use in telegraph service the advantages of compound-wound generators is apparent, as the auxiliary series winding automatically increases the strength of the field in response to load increases, and, conversely, reduces the field strength

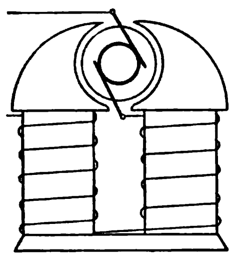


FIG. 12.—Two-pole series dynamo.

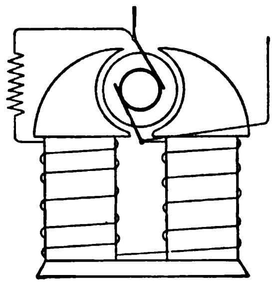


FIG. 13.—Two-pole shunt dynamo.

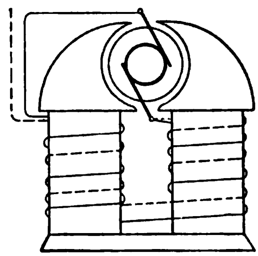


FIG. 14.—Two-pole compound dynamo.

as the load is decreased, thus furnishing practically constant voltage regardless of variations of the resistance of external circuits applied to it.

Most of the generators built for telegraphic purposes during the past 20 years have been shunt wound, but the superior advantages of compound-wound machines over the former are very likely to result in a more general employment of compound-wound machines in the future. It is possible that their general employment may be hastened by having some of the machines at present in service "compounded." In view of this it seems justifiable to devote some space to a consideration of the principles involved.

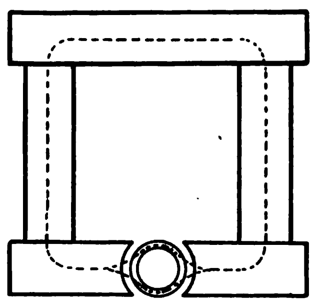


FIG. 15.—Magnetic circuit of two-pole dynamo.

Magnetic Circuit.—The magnetic circuit of a dynamo is illustrated by the dotted lines in Fig. 15. The circuit includes the iron cores of the field coils, the iron yoke joining these cores, the iron core of the armature, and the air "gap" between the pole faces and the armature. The amount of m.m.f. required in the metallic portion of this circuit is directly dependent upon the magnetic strength which it is desired to develop. This, of course, is infinitely less than that required to set up magnetism of equal density in an equal length of air space. The field winding must be designed to establish magnetism in the air-gap portion of the magnetic circuit, because that

is the seat of action, where the insulated loops of wire (the armature) are revolved, and where the e.m.f. is generated.

As previously indicated the magnetomotive force required to establish this magnetic field is expressed in ampere-turns, and it is evident that if a small current only is to be used for field excitation, a great many turns of fine wire will be needed in the field coils, while, if a large current is to be used, a much larger wire may be employed. The factor which in large measure determines the size of wire which should be used in the shunt winding is the heating of the conductor. In practice the allowable heat limit confines the permissible shunt current to about 5 per cent. of the line current.

In calculating the correct shunt winding, a magnetic flux should be provided for which will develop the desired e.m.f. with the external circuit open. When current flows in the armature coils a counteraction takes place which has a tendency to oppose field magnetization. There is also a slight reduction in the voltage of the generator due to resistance "drop" in the armature. If the line conductor is wound around the field coils a few turns, the reverse magnetomotive force developed by the armature is neutralized and the strength of the magnetic field restored to a value sufficient to reestablish normal voltage at the machine terminals. That portion of the line conductor wound over the shunt winding is called the series or compound winding.

By this arrangement the voltage at the brushes of the dynamo may be caused to increase as the current demand made upon the machine is increased. Even in dynamo manufacturing plants it is found to be somewhat difficult to determine accurately the number of turns to give the series winding of compound machines to meet given conditions. Usually the machine is "over-compounded" and a portion of the current shunted by means of a variable resistance placed across the terminals of the series coil until the correct value has been obtained.

A shunt-wound dynamo may be compounded by the addition of a series field winding. One method of approximately determining the number of series turns required is to run the generator with the external circuit open, and by means of an ammeter measure the current required in the field coils to develop normal voltage, then throw on the load (close the external circuit) and alter the resistance of the field regulator until the desired voltage is obtained. If simple compounding is the object this will be the no-load voltage, but if the machine is to be over-compounded the voltage will be proportionately larger. Now if the field current is again measured and the difference noted in the two readings of field current multiplied by the turns in the shunt coil, this value divided by the number of amperes of current flowing in the armature will give the number of turns required in the series coil.

The "shunt" winding as a rule consists of cotton-covered wire of a very

small gage wound on the core, next to the yoke. On account of the small size of conductor used the resistance is quite high and the current volume in the shunt circuit is correspondingly small. The "series" coil must be low in resistance, generally less than half that of the armature, and should be wound on the end of the cores nearest the armature so that the maximum magnetic effect may be obtained in the air gap.

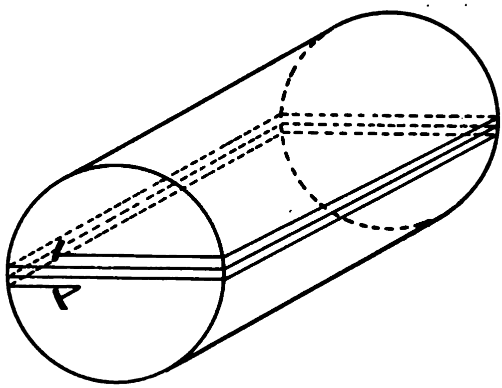


FIG. 16.—Drum wound armature, showing one coil.

Armatures.—In Fig. 10 the armature is represented as a single loop of wire. In the construction of practical dynamos each loop consists of a number of turns. As compared with one turn, when two turns are used the e.m.f. is doubled, because an equivalent voltage will be generated in each turn of wire, and in general in order to obtain a given constant potential the loops are so located and connected with respect to each other that each turn complements and adds to the e.m.f. generated by all other loops.

A completed armature consists of a core, a commutator, and a winding. The core serves to support the winding rigidly in position and also acts as a conductor of the magnetic flux from one field magnet pole-face to the other.

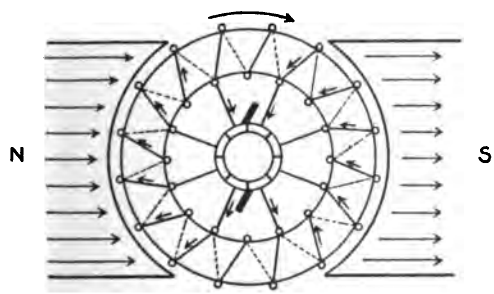


FIG. 17.—Ring wound armature.

Armatures may be either drum wound or ring wound, and may have either smooth cores or slotted cores. Fig. 16 illustrates a method of placing the armature coil on a smooth-core drum armature. A loop of three turns is shown with its terminals brought out to adjacent commutator segments.

In ring-wound armatures the conductor turns are wound around a ring-shaped core (Fig. 17) and that portion of each turn which is on the inside of the ring is practically inactive. Drum wiring obviates this "dead" winding, as in the drum type of armature each section of every conductor is on the outside of the core.

Armatures may have either closed-coil or open-coil windings. The former have all of the loops (inductors) interconnected so that with the exception

of that period when a certain portion of the winding is undergoing commutation, the voltage induced in each inductor is adding its quota of energy to the maintenance of a constant potential in the external circuit. Closed-coil winding also effects a decided advantage in reducing sparking at brushes to a minimum.

Open-coil windings provide commutator connection with the inductors in such manner that voltage produced in the coils is made use of only when each individual coil is undergoing commutation.

Closed-coil drum windings may be either lap wound or wave wound, the former method generally requires that the number of coils on the armature be the same as the number of bars on the commutator, and the number of commutator bars employed "even," to permit of equal distribution midway between the brushes, while wave winding advances around the commutator similarly to the manner in which a "wave" travels progressively from point to point.

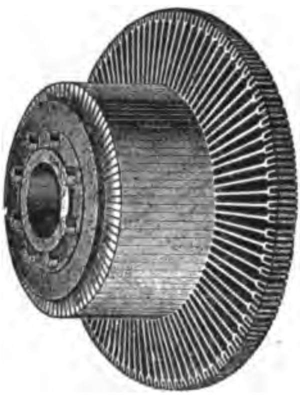


FIG. 18.—Commutator removed from armature shaft.

The Commutator.—Fig. 18 shows a view of a commutator disconnected from the armature wiring and from the shaft.

As previously stated, the current generated in an individual moving armature coil alternates from one polarity to the other as the coil cuts the lines of force passing from north to south pole during one-half of the revolution, while, as stated in connection with Fig. 11, during the other half revolution the coil cuts the lines of force in the reverse direction.

The commutator consists of a number of copper strips or segments, each one insulated from the others by means of strips of a high grade of mica. Usually the number of segments is the same as the number of armature coils, and the number of each is calculated according to the desired output of the generator. The carbon brushes which rest upon the commutator serve to lead the current from each coil at the moment it attains its maximum value. It is evident that the current gathered by the brushes will be "pulsating" in character, but by employing a large number of coils and segments the current generated is so nearly uniform that the pulsations are not noticeable in practical operations.

ELECTRIC MOTORS

Direct-current Motors.—What has been said in regard to the various elements of direct-current generators, in a general way applies to direct-

current motors, as the essential elements of one are identical with those of the other. In the case of a motor the carbon brushes resting on the commutator serve to lead the current from some external source into the coils of the armature and through the field winding, thus causing the armature to rotate, and by means of a pulley mounted on one extremity of its shaft, by gearing, or by direct mechanical connection of the shaft, furnishes mechanical power for any desired purpose. Similarly to dynamos, motors are series wound, shunt wound or compound wound. In a series motor the field consists of a relatively small number of turns of large wire directly connected in series with the line and the armature. The current in the armature coils and in the field-magnet winding is of the same value.

A shunt-wound motor has field magnets wound with a large number of turns directly connected with the brush terminals of the machine or across the terminals of the external circuit supplying the motor with current. In the case of a shunt motor the strength of the field current is independent of the current strength in the armature.

Compound-wound motors may have the two field windings connected so as to form cumulative winding, or differential winding. In the former case the magnetizing effects of both windings are in conjunction, while in the latter they are in opposition. With the cumulative winding, increasing the load of the motor increases the magnetic strength of the field, while with the differential winding an increase of load decreases the field strength.

In most towns and cities throughout the country commercial electric power is available for the purpose of driving motors. In the majority of places there is but one potential and one kind of current at hand. In some cases 110-volt direct current, in others 110-volt alternating current may be the only power available. In some cities there is no other choice but to use 200- or 250-volt alternating current, or 500-volt direct current.

It is possible to obtain electric motors designed to operate with a given potential or character of current, whether direct current or alternating current, and as in the operation of telegraph circuits four or five different voltages are needed, all that is required is to have each separate dynamo mechanically connected with and driven by a motor which may be operated by the available commercial voltage. Thus the various individual motors are operated by, say 110 volts direct current, or 200 volts alternating current, while the individual dynamos driven by these motors may have outputs ranging from 40 volts to 400 volts, or any other potentials for which they may be designed.

In practice it is best to employ the lower voltages for the operation of motors as it is found that when, for instance, 500 volts direct current is used to operate motors, heating and sparking difficulties are quite frequent and annoying. When there is a choice between 500 volts direct current and an alternating-current potential of 110 volts or 220 volts, it is common practice to employ an alternating-current motor to operate on the alternating current available,

this motor in turn being directly connected to a 110-volt direct-current dynamo, the latter furnishing current to operate the various motors which drive the dynamos generating the various telegraph currents. In this way it is possible to get away from the use of the objectionable 500 volts direct current, and at the same time effect a saving in primary-current consumption.

Also, it is usual to arrange for "auxiliary" or "reserve" power to provide against interruption to service in case the external source of power fails.

Where both alternating-current and direct-current sources of commercial power are available it is common practice to use them alternately, or to use one of them regularly and maintain the other as reserve.

Alternating-current Motors.[1]—There are three types of alternating-current motor in commercial use, namely:

Single-phase series type.
Synchronous type.
Induction motor.

The latter is the type usually employed in telegraph service for the purpose of driving small direct-current dynamos.

It has been shown in the case of a direct-current motor that the armature revolves between the pole faces of stationary field magnets.

To comprehend the forces at work in the operation of an induction motor, consider a direct-current motor armature with current traversing its coils. When the field magnets are charged, the armature will turn; but suppose the brushes which rest on the commutator are removed and the terminals of the armature coils connected to a copper ring. Then, if instead of the field magnets remaining stationary they be revolved around the armature, it follows that the magnetic lines will travel around in a circle, at the same time setting up an electromotive force in the armature coils. As these coils are short circuited by the copper ring, the current induced in the armature coils sets up a reaction, which results in a drag which pulls the armature around in a direction the same as that taken by the rotating magnetic field. In the induction motor, instead of the field magnets being revolved mechanically, the magnet windings are so connected with the external circuit that the active field moves around the circle in a given direction, thus causing the armature to rotate in unison with the constantly moving field.

The induction motor has two essential elements, the stator (Fig. 19*a*) and the rotor (Fig. 19*b*). The stator consists of a stationary framework of circular construction which serves to support the primary winding, which is connected in the manner shown theoretically in Fig. 20. The projecting cores shown are di-

[1] It has been thought best not to take up in this work the subject of the generation of polyphase alternating currents. While commercial alternating current is used to operate motors directly connected to direct-current dynamos for telegraph requirements, alternating currents are used only in a very limited way in the operation of telegraph lines.

vided into groups. In the section illustrated the poles of one group are marked (x_1), (x_2) and (x_3), the poles of a second group (y_1), (y_2) and (y_3) and those of a third group (z_1), (z_2) and (z_3). It may be observed that the consecutive poles

FIG. 19*a*.—Stator of induction motor.

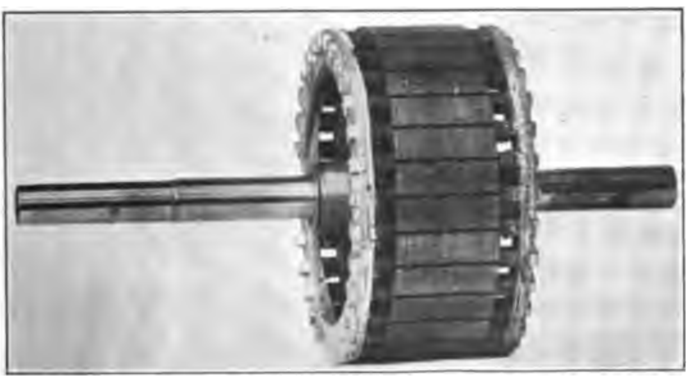


FIG. 19*b*.—Rotor of induction motor.

of any group are separated by a number of poles corresponding to the number of groups employed, and that the winding around each pole of any group alternates in direction from pole to pole, thus producing north and south poles consecu-

tively. If a three-phase alternating current be connected across the terminals, the polarity of the magnet poles of any group will be reversed twice during each cycle, and the active magnetic field progresses around the circle due to the fact that any three poles located consecutively are magnetized to a maximum one after another in order around the frame. Thus is produced the rotating magnetic field.

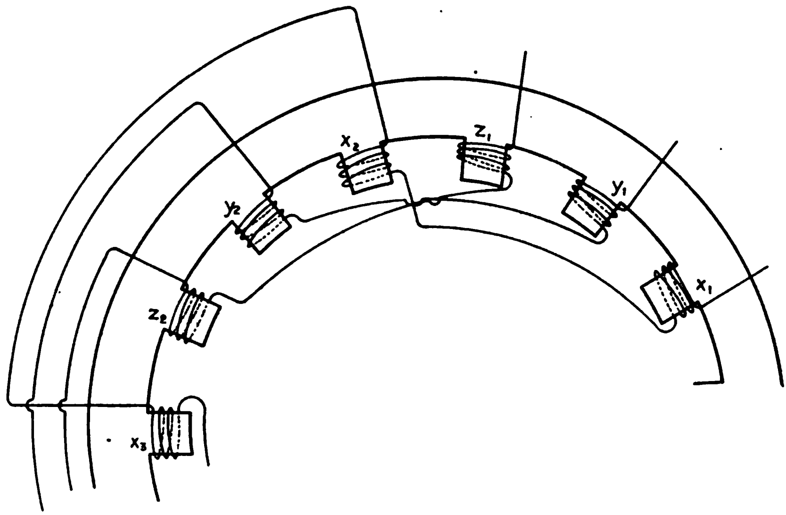


FIG. 20.—Stator magnet poles and winding connections of induction motor.

The Rotor.—The core of the rotor is made of laminated steel punchings mounted on an iron spider. Each slot in the core contains a single copper bar which is made fast to a short-circuiting ring at either end of the bars. The e.m.f. produced in the copper bars of the rotor is very low, but the force exerted upon the rotor by the revolving field is such that the induction motor is quite efficient as a source of power. Having no brushes or commutator, this type of motor is simple to operate and to maintain.

The Motor-generator.—On page 31 reference is made to the use of alternating-current motors directly connected to direct-current dynamos for the purpose of generating in the telegraph office 110 volts direct current to be used to operate the various motors which in turn are mechanically connected to the dynamos having different voltage outputs.

This type of machine is known as a motor-generator, having been given this name to distinguish it from the motor-dynamo to be described presently.

One of the standard makes of motor-generators is shown in Fig. 21. The induction motor is on the left, while on the right is shown the direct-current generator. In making up these units to meet operating conditions, the motor may be designed to operate on either alternating current or direct

current, and on whatever voltage is available, while the generator end may be designed to produce any required voltage.

Motor-dynamos.—Motor-dynamos have the two machines on one base directly connected by a steel shaft and each machine has its own field coils, see

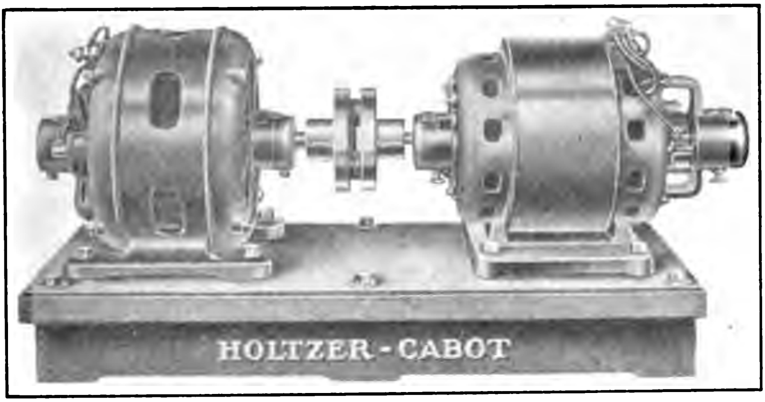


FIG. 21.—Motor generator.

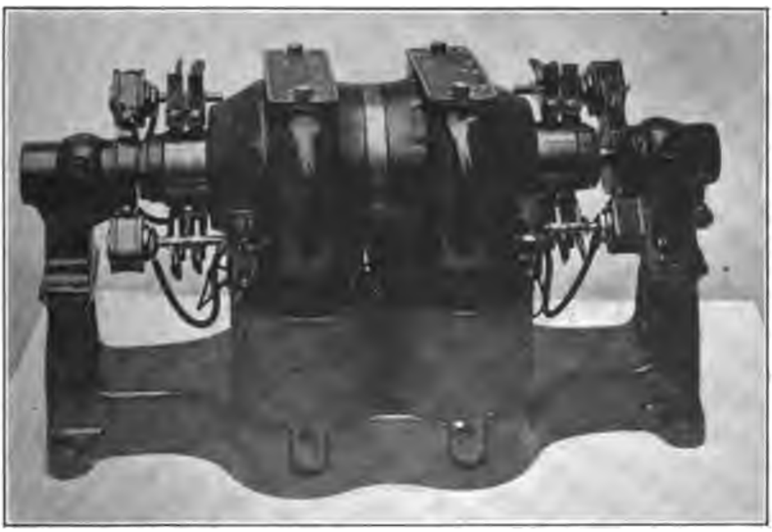


FIG. 22.—Motor dynamo.

Fig. 22. Some of these machines, notably the Crocker-Wheeler type, have the two armature windings on the same shaft but separated electrically.

Another type of machine known as the dynamotor is extensively used in telegraph work. This machine has a single field for both motor and dynamo

ends, see Fig. 23. The armatures are of the iron-clad type with slots or grooves around the outside in which the armature wires are laid and held fast by retaining wedges, readily removable when repairs are necessary. The armature core consists of sheets of soft annealed steel punchings. The copper conductors in the armature are insulated with mica strips or with oiled muslin and fibrous materials. Regulation of the voltage of the dynamo is accomplished by varying the speed of the motor by means of a controlling rheostat.

Both in the motor-dynamo and the dynamotor each end of the machine—that is, the motor end and the dynamo end—have their own commutator and brushes. The capacity of a double field motor-dynamo is determined by the capacity of the motor end and, since the dynamo operation is independent of the motor, all the methods of control practised with dynamos may be used in

FIG. 23.—Dynamotor.

these machines without affecting the motor. The dynamo field may have a shunt winding or a compound winding to insure constant pressure regardless of variations in load. In single field dynamotors, the motor and dynamo armatures are combined in one, thus requiring a single field only; that is, the primary armature winding in association with the common field which operates as a motor to drive the machine, and the secondary or dynamo winding which operates as a generator to produce the secondary current are upon the same armature core. The armature reaction of one winding neutralizes that of the other and saves energy required for magnetizing the fields.

Dynamotors can stand a somewhat greater overload than motor-dynamos but their e.m.f. drop cannot be compensated by compound winding, as in the case of the motor-dynamo. Also, since both windings of dynamotors are on the same core and under the influence of a single field the ratio of transformation cannot be varied or adjusted. Any regulation of the field strength

will simply make the machine run faster or slower, as the ratio of the turns of wire on the dynamo end of the armature to those on the motor end is unchangeable. The voltage of the dynamo end must, therefore, remain in the same ratio as the voltage on the motor end. The voltage of a single machine may be regulated by using a rheostat in series with the motor armature for reducing its speed; but this wastes energy as much as when resistances are used to cut down the secondary voltage and interferes with the constant speed of the machine to the disadvantage of the regulation of the dynamotor for constant pressure.

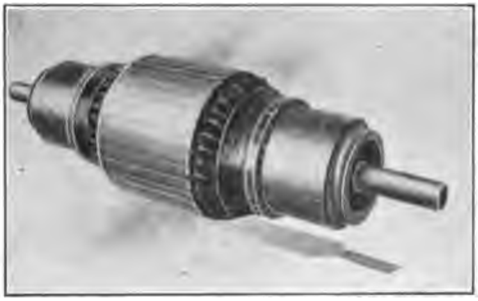


FIG. 24.—Dynamotor armature.

Figure 24 shows a view of a dynamotor armature, with the motor commutator on one end of the shaft, the dynamo armature on the opposite end, and the windings of each in the center.

Motor Current Regulation.—When an electric motor is at rest and the switch controlling the supply-current circuit is closed in the act of starting the motor, the initial rush of current through the low-resistance armature coils is excessive unless a protective resistance is placed in series with the supply mains. In order to limit the amount of current permitted to traverse the armature conductors, a rheostat or starting box is used. When a motor is started, a reaction takes place in the armature which produces a counter-electromotive force, due to the action of the inductors in the armature cutting through the magnetic lines of force produced at the field magnet poles. The counter-e.m.f. developed opposes in direction that of the supply e.m.f., thereby in a sense automatically controlling the current volume in the armature windings.

By employing Ohm's law $\left(I=\frac{E}{R}\right)$ for the purpose, the amount of current in the armature may be determined, thus:

Where I is the current in the armature,
E the impressed e.m.f. (supply voltage),
R the resistance of the armature,

Then:

$$I=\frac{E}{R}$$

Therefore, to reduce the current volume in the armature coils at the instant

of starting the motor, additional resistance must be inserted in the circuit, and with given factors we have:

$$I = \frac{E - E_1}{R + R_1}$$

Where I is the current in the armature,
E the impressed e.m.f.,
E_1 the counter e.m.f.,
R the armature resistance,
R_1 the resistance of the starting box.

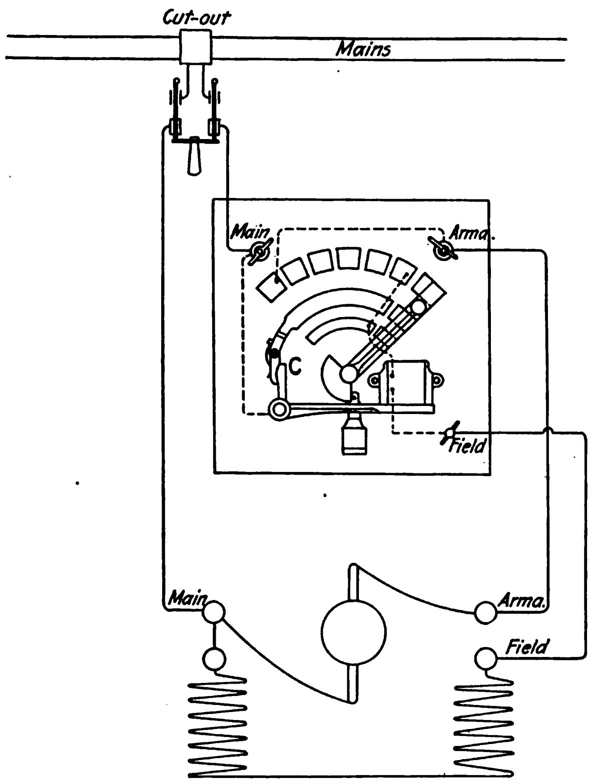


FIG. 25.—Two-pole shunt motor-starting rheostat connections.

The starting resistance in the rheostat is gradually reduced until all is cut out. The counter-electromotive force of a motor builds up as the speed of the armature increases in the same way as the voltage of a dynamo increases with increase of speed; therefore, as the starting-box resistance is gradually cut out, the counter-e.m.f. increases to its maximum, reaching that value when the full voltage from the supply mains is impressed on the motor terminals.

Figure 25 shows the wiring and connections of a 2-pole shunt motor with starting box inserted. The connections shown are the same as those used in wiring the motor end of dynamotor sets, motor-dynamo sets, and motor-generator sets, where direct-current motors are used.

An important feature of the starting box is the electromagnet shown on the right of the drawing and at the end of the row of resistance contact disks. This magnet serves to hold the rheostat arm in the "running" position as long as the magnet coil is energized by current from the supply mains. Should the supply circuit be interrupted the magnet coil is demagnetized, and, due to the force of gravity, the arm drops, thus breaking the main-line contact at C.[1]

It is evident that the automatic-release feature of the starting box protects the motor armature from the injurious effects of sudden rushes of full line voltage when the supply circuit is restored. A momentary interruption to the supply circuit does not cause the automatic release to operate as, due to momentum, the motor armature continues to run a short time after the supply current is shut off and generates an e.m.f., which furnishes current for the fields and the cut-off magnet.

Starting Boxes.—The resistance of the starting rheostat to be used in connection with a motor depends upon the amount of current required to start the motor at full-load. The resistance should be of sufficient capacity to safely carry the current indicated by the normal rating of the motor.

The word rheostat is derived from greek ρειν, to flow, and στατος, fixed. A device for regulating the flow of current.

In those cases where it is necessary continuously to use additional resistance in the armature circuit of direct-current motors for the purpose of controlling the speed, the rheostat coils must have large current-carrying capacity and the construction of the rheostat must be such that it will have ample radiating surface in order, as far as possible, to avoid excessive heating.

Most modern rheostats have the resistance wire wound on hollow asbestos, clay or porcelain bobbins, each bobbin after being wound with the desired amount of resistance wire is entirely covered with an insulating enamel which protects the unit against mechanical injury and prevents short-circuiting of turns. The various resistance units are assembled to form a complete rheostat. In case a unit becomes defective, it may be replaced without disturbing the remaining units.

Figure 26 shows the wiring of a commercial type of starting box much used in telegraph work. It may be seen that the connection between each resistance unit is brought out to a contact disk. The contacts are arranged in the arc of a circle, so that the rheostat arm pivoted at the center may make a sliding contact with the connections, cutting in or out the amount of resistance required for regulation of speed. In using a starting box in connection with a shunt-

[1] In some types of starting boxes the rheostat arm is withdrawn from the deenergized magnet through the action of a spring attached to the arm.

wound or compound-wound motor, the first contact to which the arm is moved places all of the resistance in series with the armature and the series field winding, and each successive step cuts out a portion of the resistance until the arm is moved into contact with the disk on the extreme right, when all of the resistance is cut out and the rheostat is said to be "set" in the running position.

It should be borne in mind that starting resistances are designed and intended for momentary use only, and the rheostat arm should never be stopped on any intermediate step longer than a second or two, as the excessive heating of the coils is likely to cause burn-outs.

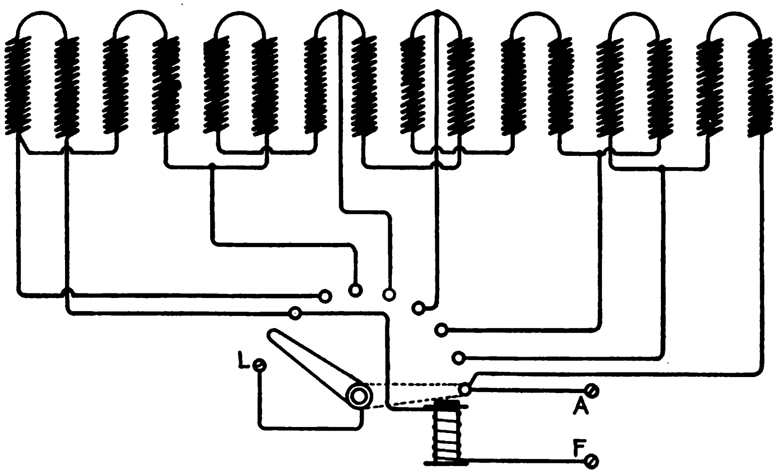


FIG. 26.—Connections and wiring of motor-starting rheostat.

The total resistance of motor starting boxes usually is such that when the rheostat arm is moved to the first contact, one and one-half times the full torque current of the motor will flow through the armature winding. To start a motor from a position of rest and accelerate it to full speed within a reasonably short time requires one and one-half times the full torque current of the motor at full-load. Although the duration of this excess of current is brief, it is necessary to protect the armature by employing a device which will open the motor circuit when a current 50 per cent. above its normal rating is permitted to flow for more than a fraction of a minute.

An enclosed fuse is generally employed for the purpose. In a given case, for instance, a fuse may be employed which has been designed to "open" when a current 50 per cent. above its rated capacity flows through it during 30 seconds time. If the fuse employed is of the 20-ampere class, a current of 30 amperes flowing through it for a period of 30 seconds would cause a temperature rise in the fuse wire which would melt it and thus open the circuit of which the fuse forms a part.

Fuses in Motor Circuits.—The necessity for employing starting resistance

in motor circuits is apparent from the knowledge that the resistance of the armature winding is very low, about 0.4 ohm. In cases where 110-volt supply current is used to operate the motor, if no starting resistance were inserted, theoretically, there would be a current of 275 amperes in the armature at the instant the main switch is closed. This would cause destructive sparking and possibly melt the soldered connections.

When a starting resistance is employed, and gradually cut out by means of the rheostat arm as the motor armature accelerates and generates an opposing e.m.f., the disastrous effects of excessive initial current are avoided. In view of the above, the necessity for careful handling of the starting resistance is apparent.

In order to provide against mishap to the starting resistance or to the motor —overload—it is customary to "fuse" the motor circuit so that a current large enough to cause heating of the conductors or connections will not be permitted to exist long enough to do damage.

The cartridge type of enclosed fuse (the form approved by the fire underwriters) consists of a short length of wire made of lead in combination with a certain percentage of tin. Tin fuses (melts) at a temperature of 235° C., and lead at 325° C. In making fuse wire a squirting process is employed, similar to that used in making incandescent lamp filaments. The fuse wire is packed in an asbestos wrapping and enclosed in a pasteboard tube equipped with brass thimbles at either end, each end of the fuse wire being soldered to one of the thimbles.

Fuse blocks are equipped with spring brass clips set a sufficient distance apart to accommodate a particular length of fuse; this construction is quite convenient for quickly replacing defective fuses.

Motor circuits are fused on both sides, otherwise, one side becoming grounded at one point and the other side at another point, a circuit might be established with no fuse in action.

Overload Motor-starters.—The overload attachment to a motor-starter consists of a magnet the coils of which carry the total current consumed by the motor. When the current becomes excessive, the magnet attracts its armature and completes a short circuit around the terminals of the retaining magnet which holds the rheostat arm at the "full on" position. The short circuit is closed by means of two brass posts conveniently mounted on the face of the starter. The holding magnet is thus demagnetized, the rheostat arm flies back to the "off" position, inserting the total resistance of the starter, opens the circuit and stops the motor.

Underload Release.—Diagram 26 shows the wiring of a standard type of starting box including a no-voltage release attachment.

A type of "remote-control" motor-starter used in telegraph work is illustrated in the photographic reproduction, Fig. 27.

In the larger telegraph centers it is necessary to have a number of 50-volt

and 100-volt potentials available for intermediate battery purposes. For, while ordinarily the regular battery arrangements are sufficient to take care of circuit requirements, there are occasions when, temporarily at least, additional battery is required to maintain currents of a requisite strength to satisfactorily operate lines.

Inasmuch as these extra battery facilities are for emergency service and are used only for short periods during the day, a switching arrangement is provided whereby the switchboard attendants in the main operating-room may, at will, start and stop any one or all of the machines intended for intermediate battery purposes, even though the machines are located in a part of the building remote from the operating-room.

FIG. 27.—Solenoid motor-starter.

Figure 27*a* shows the connections of the automatic starter used for this purpose. The motor supply mains are connected to the switch *sw* which regularly is left closed. The coils C are solenoids having double windings, which when energized pull up the plungers P. To the lower extremity of each plunger is attached metal or carbon contact plates P_1 which act as a switch to open or close the armature and field circuits of the motor in response to the operation of the plungers. If the circuits are traced it may be noted that the resistance coil S remains in series with the armature for a short time after the motor circuit is closed, and is short-circuited only after the armature has speeded up sufficiently to avoid the effects of the initial inrush of current. Four wires are shown leading from the engine-room, or dynamo-room to the operating-room switchboard, where they terminate in a specially constructed double-contact pin-jack.

The insertion of a double-conductor plug in the jack closes both the motor and dynamo circuits. The "wedge" end of the connecting cord is inserted in series with the line at the spring-jack as shown on the right.

Alternating-current Motor-starters.—Alternating-current motors take a large current when started under load, so large in fact that unless proper provision is made against it, serious fluctuation of line voltage occurs when any motor on the circuit is started up. To avoid this a means is employed whereby a reduced voltage is applied to the motor at starting, this is gradually increased until the full-line voltage is applied to the motor terminals when the rotor has reached full speed.

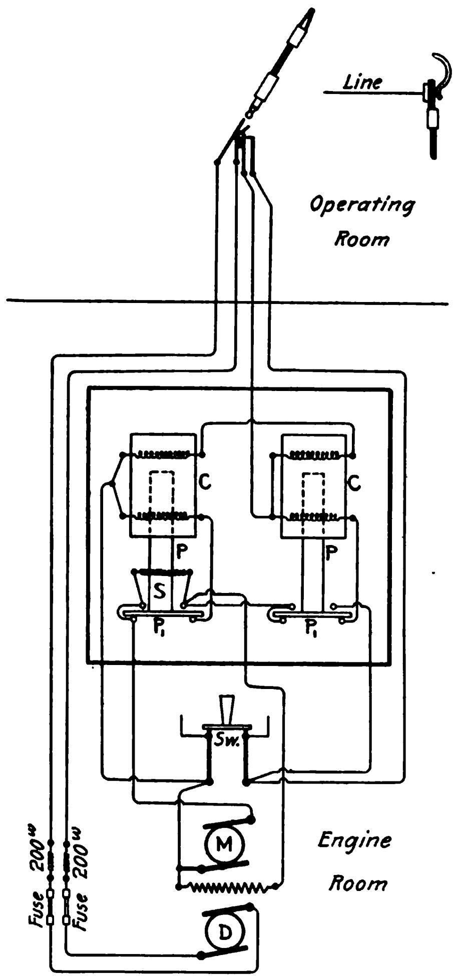
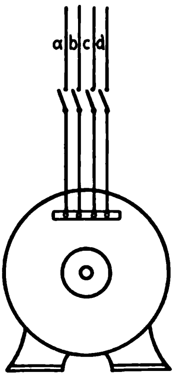


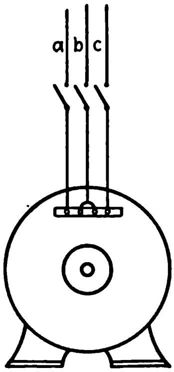
FIG. 27a.—Connections and wiring of solenoid motor-starter.

The usual type of controller employed is called an auto-starter, which consists of a specially designed switching system, operating in conjunction with two auto-transformers. The transformers are in circuit with the supply mains. Each transformer consists of a winding from which a series of taps are made, each tap providing for a different voltage. As these taps are successively connected with the motor by means of the switch an increasing voltage value is applied to the motor terminals until finally the full line-voltage is thrown on. The losses due to transforming continue only during the starting process because when the full line-voltage is applied the auto-transformers are disconnected from the circuit. In moving the auto-starter handle from one notch to the next the circuit is for an instant entirely interrupted. Under ordinary conditions breaking and making the circuit would cause violent sparking, the contacts, however, are made and broken in a chamber filled with oil, thus materially reducing the liability of sparking.



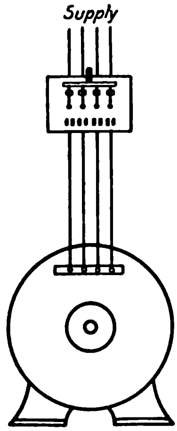
a

FIG. 28*a*.—Four-wire two-phase motor connections.



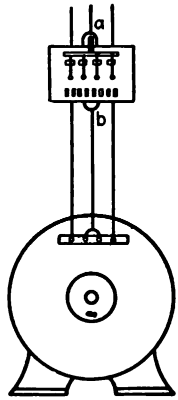
b

FIG. 28*b*.—Three-wire two-phase motor connections.



c

FIG. 28*c*.—Four-wire, two-phase motor connected through an auto-transformer.



d

FIG. 28*d*.—Three-wire, two-phase motor connected through an auto-transformer.

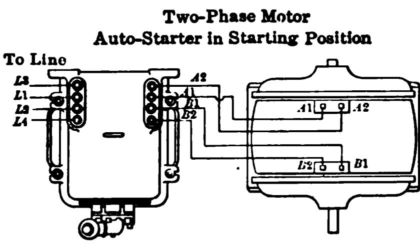


FIG. 29.

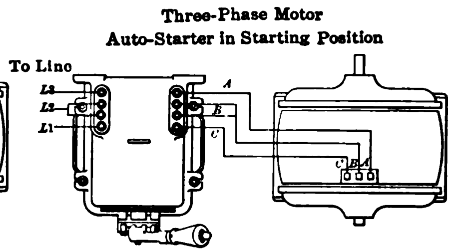


FIG. 30.

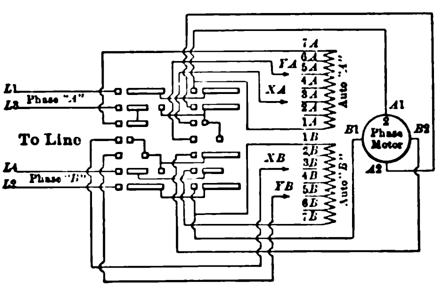


FIG. 31.

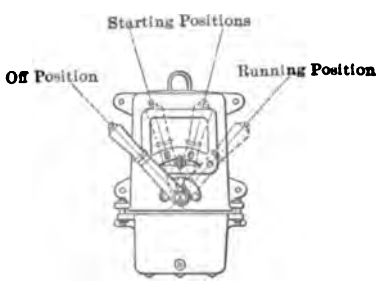


FIG. 32.

FIGS. 29, 30, 31, 32.

Figure 28*a* shows the connections of a two-phase squirrel-cage motor; the wires *a* and *b* belong to one phase and the wires *c* and *d* to the other. In some instances the two wires belonging to one phase are marked *a* and the two wires of the other phase marked *b*, but in general any two wires which are found to have voltage between them belong to one phase or the other. Fig. 28*b* shows the connections of a three-wire two-phase system, the wire *b* or "common return" being connected jointly to the two center terminals. Fig. 28*c* shows a two-phase four-wire motor connected through an auto-transformer. Fig. 28*d* shows a two-phase three-wire system connected through an auto-transformer.

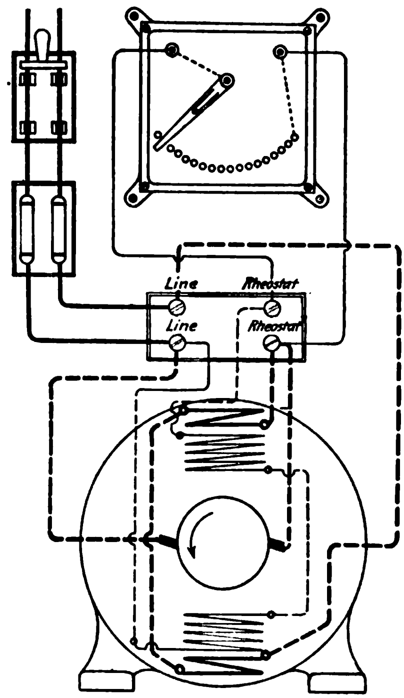


FIG. 33.—Complete wiring connections of a two-pole compound dynamo.

After a four-wire two-phase motor has been connected up, should it develop that rotation is in a direction the reverse of that desired all that is necessary is to interchange the two wires of one phase; that is *a* and *b*, or *c* and *d*.

Figure 29 shows the connections of a two-phase motor and auto-starter.

Figure 30 shows the connections of a three-phase motor and auto-starter.

Figure 31 shows the connections and internal wiring of a four-wire two-phase auto-starter of the oil-immersed type. The motor terminal markings are shown on the right, namely, *A*1, *A*2, *B*1, *B*2.

Figure 32 shows a view of the auto-starter complete with the handle in the "off" position, while the starting and running positions are shown in dotted lines.

Dynamo Current Regulation.—The output of dynamos may be controlled by regulating the speed of the dynamo armature, or by regulating the current strength in the field winding of the dynamo.

When motor-generators or motor-dynamos are employed, the first-named method may be availed of by inserting a field regulating rheostat in the field circuit of the motor as explained in connection with Figs. 23 and 24. Regulation of voltage through control of the field strength of the generator is accomplished by inserting a rheostat as shown in Fig. 13, which shows the internal wiring and terminal connections of a shunt-wound 2-pole generator.

The connections of a compound-wound 2-pole dynamo are shown in Fig. 33.

CHAPTER IV

STORAGE BATTERIES

CURRENT RECTIFIERS; MERCURY-ARC AND ELECTROLYTIC

The names storage battery, secondary cell, and accumulator have been given to that type of battery which consists of elements capable of absorbing electrical energy and storing it in the form of chemical energy.

The type of storage cell most generally employed in telegraph work consists of a number of lead plates immersed in a dilute solution of sulphuric acid. Alternate plates of a cell are joined together making up the positive element; the balance of the plates similarly joined constitute the negative element. See Figs. 34, 34*a* and 34*b*.

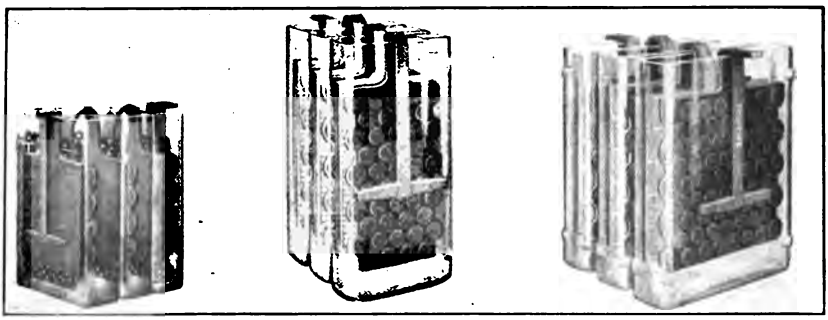


FIG. 34. FIG. 34*a*. FIG. 34*b*.

FIGS. 34, 34*a*, 34*b*.—Storage cells.

The negative plate consists of a lead grid in the interstices of which is fixed a litharge paste consisting of sulphuric acid and oxide of lead, this, in forming, changes to metallic gray lead. The positive plate of red lead in forming changes to peroxide of lead. The electrolytic solution is made up of 1 part sulphuric acid (H_2SO_4) and 5 parts distilled, or rain water.

Externally the direction of current is from peroxide of lead plate through the connecting circuit and back to the negative, or lead "sponge" plate. This is the condition when the cell is discharging. Internally, or when the cell is being charged from an external source of e.m.f. the current is in the reverse direction.

There are several methods of charging storage batteries, and the method employed in a given installation is dependent upon local conditions, as regards available sources of charging current. In many instances it is economical to use the existing 110-volt lighting current for the purpose. Where

commercial or private lighting circuits are not at hand, a gas-engine-driven electric generator may be used to charge the cells. In considering the installation of a storage battery plant, the first thing to be determined is the desired output or capacity of the plant. Obviously, this depends upon the number of lines and circuits to be fed and the amount of current in amperes, or fractions thereof, required to operate such circuits. If, for instance, there were 10 wires to feed, each requiring 40 m.a. current, the 10 wires would require 0.4 ampere, and if the wires were to be operated 24 hours per day, the required ampere-hours per day would be

$$0.4 \times 24 = 9.6 \text{ ampere-hours per day.}$$

This would be the maximum demand made upon the battery, as the above calculation is based on the possibility of the circuits being closed all of the time. In practice it is found that, considering the average of a large number of lines, circuits are closed a little less than half the time.

Two types of storage cell in common use are the "couple" type, and the "multiple" type. In the couple cell there are but two plates. The multiple cell has three or more plates. The terminals of the plates in multiple cells are either burned together or bolted with lead-covered bolts.

Storage battery plates are made up in several sizes which are considered standard.

Type "E" plates are 7 3/4 in. × 7 3/4 in. = 60 sq. in.
Type "F" plates are 10 1/2 in. × 10 1/2 in. = 110 sq. in.
Type "G" plates are 15 1/2 in. × 15 1/2 in. = 240 sq. in.

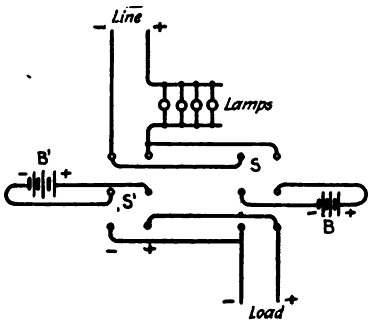
The normal charging rate of the "E," "F," and "G" types of cell is approximately 0.08 ampere per square inch of positive plate. Thus to find the normal charging rate of a type "G" cell having 6 positive plates and 7 negative plates, calculate as follows:

$$6 \times 240 \times 0.08 = 115.20 \text{ amperes.}$$

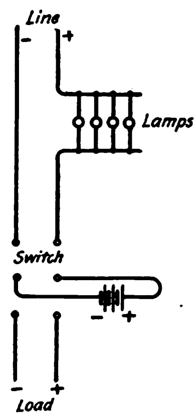
When 110-volt lighting mains are used to charge storage cells a suitable number of incandescent lamps should be inserted in the lighting circuit, as shown in Fig. 35, in order to take from the circuit a current sufficient to charge the battery. An automatic break switch is inserted in the circuit so that in case the primary current is interrupted the charging circuit will be opened and the storage battery prevented from discharging back through the charging mains. The connections of this switch are such that an electromagnet energized by current from the charging mains actuates an armature which when the current is flowing acts as a switch to keep the circuit closed. When the charging circuit is interrupted, the electromagnet is deenergized, thus releasing the armature and opening the circuit. There are several different types of automatic switch which may be used for the purpose. One device in common use operates in the reverse way to that just described, that is, the armature mounted above

the magnet core is adjusted to remain "open" when normal current traverses the winding of the magnet, while the increment of current due to short circuit, attracts the armature and opens the circuit.

When a cell has been fully charged the active agent in the positive plate consists of lead peroxide, and the negative plate has been converted into "spongy lead." During the time a storage cell is being discharged the active material in both positive and negative plates is being converted into "lead sulphate," due to the extraction of the sulphion from the acid of the electrolyte. After discharge, when a cell is recharged, the positive



No. of Cells to be Charged in Series	Voltage of Resistance Lamps	BT	CT	PT	BT
1-9	110	1-16 c. p.	3-16 c. p.	3-32 c. p.	5-32 c. p.
10-18	110	1-32 c. p.	2-32 c. p.	4-32 c. p.	6-32 c. p.
19-27	110	1-32 c. p.	5-16 c. p.	5-32 c. p.	7-32 c. p.
[illegible]	110	2-32 c. p.	4-32 c. p.	8-32 c. p.	12-32 c. p.
	50-60	1-16 c. p.	2-16 c. p.	4-16 c. p.	6-16 c. p.



FIGS. 35, 36.—Storage battery "charging" and "discharging" circuits.

plate is converted back into lead peroxide, and the negative plate into spongy lead. It is only the material of which the buttons are made that undergoes chemical changes, as the supporting grid, consisting of a lead-antimony combination is acted upon only in a small degree. A peculiarity of lead (due to the formation of a coating of sulphate) is that it is insoluble in sulphuric acid.

The statement above made, to the effect that during discharge the active material in both positive and negative plates is converted into lead sulphate, is based on the latest and most generally accepted theory of the action that takes place.

Figures 35 and 36 show the connections of storage battery charging and discharging circuits as usually arranged.

INSTALLATION AND MANAGEMENT OF STORAGE CELLS

Location of Battery.—The proper location of the battery is important. It should preferably be in a separate enclosure or compartment, which should be well ventilated, dry and of moderate temperature.

The ventilation should be free, not only to insure dryness, but to prevent chance of an explosion, as the gases given off during charge form an explosive mixture if confined. For this reason never bring an exposed flame near the battery when it is gassing.

To obtain the best results, the temperature should be between 50° and 80° F. If the temperature is very high, that is, over 80° F., for any great length of time, the wear on the plates is excessive. If the temperature is low, no harm results, but the available capacity is reduced during the period of low temperature.

Installing Battery.—Place the jars, after they have been cleaned, in position on the sand trays, which should previously be filled evenly with the top with fine dry bar sand. The trays, which should be separated by an air gap, rest on glass insulators, which in turn rest on stands or shelves. The cells should be so located in the room that they will be easily accessible and if practicable should be in one tier; where two or more tiers are necessary, ample head room over each tier should be allowed for. If sand trays are not provided, the jars may rest directly on a board or plank, in sections of not more than 10 cells each, the plank being insulated from the stand or shelf by glass insulators, and an air gap left between the section rests.

Plates of opposite polarity, except the terminal plates, are burned together by a connecting strap, forming a "couple," and are placed in adjoining jars; the positive plates are of a brownish color, the negatives of a light gray. Before placing the couples in the jars, the straps should be bent over a piece of wood 3/4 inch thick, the top edge of which is rounded. After removing from the form, the straps should be still further bent until the lower edges of the plates touch; then by gently springing them apart when putting into the jars the plates of adjacent couples will not have a tendency to get together and short circuit. In bending, care should be taken that only the connecting strap is bent, as the burned joints must not be subjected to undue strain. The plates must be placed in the jars, so that in each there will be both a positive and a negative plate and the sections of the battery must be connected, preferably by lead tape, so that the positive and negative terminals, which are the single plates, will be connected a positive and negative together in each case. If couples or sections are installed in the wrong direction, the plates will be seriously injured. Rubber separators are used only in Type "BT" cells; in other types no separators at all are used.

Connecting up the Charging Circuit.—Direct current only must be used for charging. If alternating current alone is available, a current rectifier must be used for obtaining direct current. Before putting the electrolyte into the cells the circuits connecting the battery with the charging source must be complete, care being taken to have the positive pole of the charging source connected with the positive end of the battery, and the negative pole with the negative end of the battery. If a suitable voltmeter is not at hand, the polar-

ity may be determined by dipping two wires from the charging terminals into a glass of water to which a teaspoonful of table salt has been added, care being taken to keep the ends at least 1 in. apart to avoid danger of short circuits. Fine bubbles of gas will be given off from the negative pole.

Electrolyte.—The electrolyte used for filling new cells is dilute sulphuric acid of a specific gravity of 1.180 or 22° Baume (except Type "ET," see note), as shown on the hydrometer at a temperature of 70° F. When new electrolyte is required it can be made by mixing pure sulphuric acid (1.840 sp. gr., or 66° Baume) and distilled water in the proportion of 1 part acid to 5 1/4 of water, by volume, for 1.180 sp. gr. When mixing, pour the acid slowly into the water (not the water into the acid) and thoroughly stir with a wooden paddle. The final specific gravity must be read when the solution is cool. A metal vessel must not be used for mixing or handling the solution; a glazed earthenware crock or a lead lined tank is suitable, or a wooden vessel which has not been used for any other purpose, such as a new wash tub, can be used for mixing, but not for storing, the electrolyte. The electrolyte must be cool when poured into the cells.

NOTE.—For Type "ET" cells, when being first put into commision, electrolyte of 1.210 sp. gr., or 25° Baume must be used. If the electrolyte is to be mixed on the ground, the proportions of acid (of 1.840 sp. gr., or 66° Baume) and water are 1 part acid to 4 1/2 of water (by volume).

With the battery properly installed and the charging connections made ready, the electrolyte can be poured into the cells, filling until the plates are covered 1/2 in.

Initial Charge.—The charge should be started at the normal rate (see "Table of Ratings,") as soon as the electrolyte is in the cells and continued at the same rate, provided the temperature of the electrolyte is well below 100° F., until there is no further rise or increase in either the voltage or specific gravity and gas is being freely given off from all the plates. Also, the color of the positive plates should be a dark brown or chocolate, and the negatives a light slate or gray. The temperature of the electrolyte should be closely watched, and if it approaches 100° F. the charging rate must be reduced or the charge stopped entirely until the temperature stops rising. From 30 to 40 hours at the normal rate will be required to complete the charge; but if the rate is less, the time must be proportionately increased. The specific gravity will fall somewhat after the electrolyte is added to the cells, and will then gradually rise as the charge progresses, until it is up to 1.210, or thereabouts. The voltage for each cell at the end of the charge will be between 2.5 and 2.7 volts, and for this reason a fixed or definite voltage should not be aimed for. It is of the utmost importance that the initial charge should be complete in every respect. If there is any doubt, it is better to charge too long than risk injury to plates by stopping the initial charge before it is complete.

After the completion of a charge (initial or with the battery in regular service) and the current off, the voltage will quite rapidly fall to about 2.05 volts per cell and there remain while on open circuit, falling to 2 volts when the discharge is started.

Operation; Battery in Service.—Excessive charging must be avoided, nor must a battery be undercharged, overdischarged or allowed to stand completely discharged.

The battery should be preferably charged at the normal rate. It is important that it should be sufficiently charged, but the charge should not be continued beyond that point. Both from the standpoint of efficiency and life of the plates, the best practice is the method which embraces what may be called a regular charge, to be given when the battery is from one-half to two-thirds discharged, and an overcharge to be given weekly if it is necessary to charge daily, or once every two weeks if the regular charge is not given so often.

The regular charge (at or as near normal rate as possible) should be continued until the voltage across the battery has risen to a point which is 0.05 to 0.10 volts per cell below what it was on the preceding overcharge, the charging rate being the same in both cases; for instance, if the maximum voltage per cell attained on the overcharge is 2.52, the voltage per cell to be reached on the regular charge is from 2.42 to 2.47 volts per cell. In cases where it is possible to accurately determine the amount of discharge in ampere-hours, the following method is permissible and may be found more suitable, particularly where there is difficulty in reading the voltmeter closely: charge at the normal rate until the number of ampere-hours charged exceeds the preceding discharge by from 5 to 15 per cent.

The overcharge (at the same rate as regular charge) should be continued until the voltage across the battery has been at a maximum for one hour, five successive 15-minute readings showing no further rise and all cells are gassing freely. If rate is less than normal, the time at maximum must be proportionately increased.

On discharge the voltage should not be allowed to fall below 1.75 volts per cell, with current at normal rate; the limiting voltage, however, is higher if the rate is less than normal, and lower if the rate is more than normal.

Inspection.—Once every two weeks, on the day before the overcharge, a specific-gravity reading[1] of all cells should be taken, and likewise all cells should be carefully examined to see that the plates are not touching each other or otherwise short circuited and have normal color. Near the end of the overcharge all cells should be looked over to see that they are gassing freely.

Low Cells; Indications and Treatment.—Falling off in specific gravity or voltage relative to the rest of the cells. Lack or deficiency of gassing on

[1] On Type "BT" cells an individual cell-voltage reading, taken just before the end of overcharge, may be substituted for the specific-gravity reading, taking, however, a gravity reading at least once every three months.

overcharge as compared with surrounding cells. Color of plates markedly lighter or darker than the surrounding cells.

In case of any of the above symptoms being noted, inspect the cell carefully for the cause and remove at once. Short circuits are to be removed with a thin strip of hard rubber or wood; never use metal.

If, after the cause of the trouble has been removed, the readings do not come up at the end of overcharge, the battery as a whole, or preferably the section in which the low cell is located, should receive a separate or extra charge.

Impurities in the electrolyte will also cause a cell to work irregularly. Should it be known that any impurity has gotten into a cell, it should be removed at once. In case removal is delayed and any considerable amount of foreign matter becomes dissolved in the electrolyte, this solution should be replaced immediately, thoroughly flushing the cell with water and putting in new electrolyte of 1.210 sp. gr.

Sediment.—The accumulation of sediment in the bottom of the jars must be watched and not allowed to touch the plates, as, if this occurs, rapid deterioration will result. To remove the sediment, the simplest method is to lift the couples out of the jars after the battery has been fully charged, draw or pour off the electrolyte, clean out the jars and get the couples back and covered with electrolyte again as quickly as possible, so that there will be no chance of the plates drying out. Some new electrolyte (1.210 sp. gr.) will be required to replace that lost. When work is completed charge until voltage has been at maximum for five hours and adjust gravity to standard.

Evaporation.—Do not allow the surface of the electrolyte to get down to the top of the plates; keep it at its proper level (1/2 in. above the top of the plates) by the addition of pure water only, which should be added at the beginning of a charge, preferably the overcharge. To transport or store the water, use clean, covered glass or earthenware vessels.

Restoring Lowered Specific Gravity.—It will not be necessary to add new electrolyte, except at long intervals (once every year or two), or when cleaning. When the specific gravity, with the cells in good condition and at full charge and normal temperature (70° F.), has fallen to 1.190, it should be restored to standard (1.205 to 1.215) by the addition of new electrolyte instead of water when replacing evaporation. To correct to normal temperature, subtract one point (0.001 sp. gr.) for each 3° F. below 70° and add one point for each 3° F. above 70°; for instance, electrolyte which is 1.213 at 61° and 1.207 at 79° will be 1.210 at 70°.

Battery used but occasionally; Putting the battery out of commission and in again.—If the battery is to be used at infrequent periods, then a refreshing charge should be given once every two weeks. If the use of the battery or any of its cells is to be discontinued for a considerable time, then it must be treated as follows: After thoroughly charging, siphon or pour off the electrolyte (which

may be used again) into thoroughly cleaned carboys or other glass receptacles which can be covered to keep out impurities, and as each cell becomes empty, immediately fill it with fresh, pure water. When water is in all the cells, allow the battery to stand 12 or 15 hours; and then draw off the water and the battery can then be allowed to stand without further attention. To put into service again, proceed as in the case of the initial charge; but use for all types, either new electrolyte of 1.210 sp. gr., or if the old electrolyte has been saved, add enough new of 1.210 sp. gr. to replace loss. If the gravity after the first charge is low, it should be restored to standard.

Obtaining Additional Life.—When the condition of the battery as a whole is such that, due to normal wear on the plates, it will not do its regular work, considerable additional life can be obtained from the plates by removing the couples from the jars and bending the connecting strap in the reverse direction, so that the sides of the plate which were against the jar will face each other in the same cell; in other words, the insides of the plates become the outsides.

TABLE OF RATINGS

Type	LT	BT	CT	PT	ET
Size of plates	$3\frac{1}{2}'' \times 1''$	$4'' \times 3''$	$5'' \times 5''$	$8\frac{3}{4}'' \times 5''$	$7\frac{3}{4}'' \times 7\frac{3}{4}''$
Normal rate (amperes) charge and discharge.	$\frac{1}{5}$	$\frac{3}{4}$	$1\frac{1}{2}$	3	$4\frac{1}{2}$

THE EDISON NICKEL-IRON STORAGE CELL

While on the subject of storage batteries, it may be well to give a brief description of the Edison nickel-iron storage cell recently brought out, and which is the latest development in this country in the manufacture of secondary cells. So far, the new Edison battery has been employed chiefly in operating the motors of electric vehicles, but inasmuch as its construction is a new departure in storage-battery engineering and as its performance has been quite satisfactory, its possibilities as an efficient and economical source of e.m.f. may in the course of time insure it a more extended use commercially. The latest type of the Edison cell is known as "type A." Two sizes of cell, known as A-4 and A-6, have four and six positive plates respectively. Instead of employing a lead-peroxide and acid-electrolyte combination as is usual in the construction of lead storage cells, the Edison cell employs active materials consisting of nickel and iron oxides for the positive and negative electrodes, in combination with an alkaline electrolyte, the latter being a solution of caustic potash in water. The retaining vessels are made of sheet steel, all seams being

welded by the autogenous method. The retaining-cans are electroplated with nickel, which protects the steel from rust.

A type A-4 cell contains four positive and five negative plates. Each positive plate consists of a grid of nickelplated steel supporting the active material which is contained in two rows of tubes, 15 in each row. The tubes are made from thin sheet steel, perforated and nickelplated, each tube being reinforced by eight ferrules which preserve correct alignment and prevent expansion of the tubes. The active material in the tubes is intermixed with thin flakes of pure metallic nickel which are produced by an electrochemical process. The negative element or plate consists of 24 rectangular pockets supported in a nickelplated steel grid, in three horizontal rows. These pockets are the same as the tubes in the positive element except in shape and dimension. Each pocket is filled with oxide of iron or iron rust. When the pockets have been assembled in the negative grid, the whole is subjected to a heavy pressure which produces a solid and compact unit. The plates are assembled in the container in a manner similar to that employed in assembling lead cells. The electrolyte consists of a 21 per cent. solution of caustic potash in distilled water.

It is claimed that the Edison cell does not deteriorate when left uncharged and that it is not injured by overcharging.

CURRENT RECTIFIERS

The Mercury-arc Rectifier.—Current from an alternating-current source may be changed to direct current by means of current rectifiers. The diagram, Fig. 37, shows theoretically, the connections of the "mercury" rectifier. The alternating current to be rectified is supplied through the transformer shown at the top of the diagram.

When a current of electricity is made to flow in a given direction between two points in a circuit separated by a gap containing vapor of mercury, should the direction of current be changed suddenly, the current will be interrupted due to a peculiar characteristic of mercury which in effect opposes a change in direction of current.

Referring to Fig. 37, E represents a glass tube or globe containing a deposit of mercury and exhausted of air. Terminals A, A', B and C are sealed in the glass. If at a given instant the terminal X of the alternating-current supply circuit is positive, the terminal A is then positive and the arc will flow between the terminal A and the mercury terminal B, continuing on through the storage battery F, through reactance coil D_1 and back to negative terminal Y of the transformer. An instant later when the impressed e.m.f. has dropped to a value insufficient to maintain the arc against the counter-e.m.f. of the arc and the load, the reactance coil D_1 which has been charging now produces an inductive discharge in the same direction as formerly, which assists in maintaining the arc until the e.m.f. of the supply circuit has passed through zero; reversed, and built up in the opposite direction sufficiently to strike an arc between A'

and the mercury terminal B. The arc now being maintained between A' and B is supplied with the combined current from the transformer and from the coil D_1. Obviously the current in the alternating-current supply circuit is constantly changing in direction, thus tending to enter at A and leave at A', and in the reverse direction to enter at A' and leave at A a great number of times per second. The only action, however, which can take place is that the first impulse enters at A' and leaves at B and, due to the maintenance of the arc as before explained, the next impulse will enter at A and leave at B. Therefore the current continuously flows out at B in the same direction (direct current). The choke coils D and D_1 obstruct alternating current, but permit direct current to pass through. Were it not for the action of these coils a current wave coming down either side would divide and be neutralized.

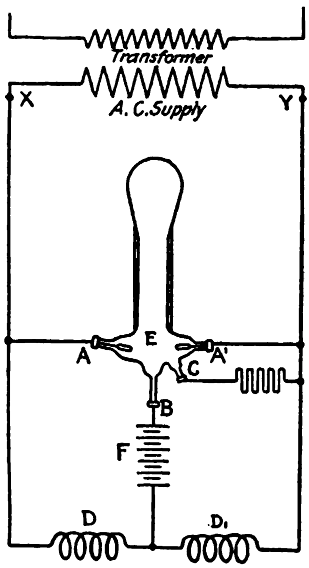


FIG. 37.—Mercury-arc current rectifier.

Electrolytic Rectifiers.—One type of electrolytic rectifier (the "Hickley") consists of a solution or electrolyte, such as phosphate of soda, in combination with carbon and aluminum electrodes, contained in a vessel V, Fig. 38, to which are attached radiator loops R permitting circulation of the solution (necessary on account of heat developed in the cell) thereby preventing the weakening of the electrolyte. The direct current supplied by the rectifier is, of course, pulsating, but owing to the condenser effect of the cells whereby a portion of the current is recovered, currents are derived which are sufficiently steady for telegraph requirements. With this type of rectifier 80 volts direct current are procurable from 110 volts alternating-current primary voltage. The durability of the electrolyte and the electrodes of this rectifier depends upon the amount of energy delivered, but if not overworked the rectifier will not require renewal oftener than once each year, assuming daily operation. A suitable transformer T is utilized to give either higher or lower voltage than that supplied by the available alternating-current mains, the rectifier being designed to supply e.m.fs., ranging from 6 to 1,000 volts. These rectifiers may be operated on any alternating-current frequency from 25 to 133 cycles.

The electrolytic rectifier is based purely upon the principles of electrolytic action as utilized in various branches of the electrical arts.

If two rods of aluminum are placed in a vessel containing an alkaline solution such as carbonate of soda or phosphate of soda, and an attempt is made to pass a current of electricity from one rod to the other through the

solution, it is found that during a brief interval current will flow and then entirely cease. If, however, one of the aluminum rods is replaced by a rod of carbon, iron, or platinum, it at once develops that current will flow from the carbon to the aluminum electrode, but not in the reverse direction. The reason is given that the carbon gives off a gas which is dissipated through the electrolyte, while the aluminum electrode (if positive) retains a portion of the gases generated. These gases, hydrogen and oxygen, unite with minute portions of the aluminum and form hydroxide of aluminum. The aluminum electrode being coated with hydroxide prevents the flow of current from it; therefore, when an alternating current is supplied to the two electrodes it is only when the current is positive to the carbon that current flows. It is evident that the negative impulse is obliterated, and that the secondary current delivered through the rectifier will consist of the succeeding positive impulses only. With an alternating current of low frequency it would seem that the utilization of alternate impulses only would produce a secondary current so slowly pulsating that it would not be sufficiently continuous for practical requirements, but the condenser effect above referred to operates to tide over the no-current intervals, and in practice it is found that the rectified currents are quite satisfactory as direct currents.

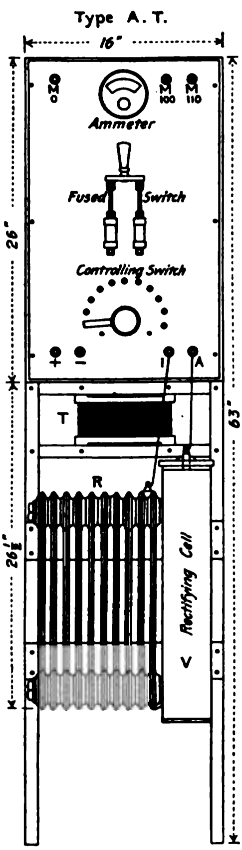


FIG. 38.—Electrolytic rectifier and switch panel.

MANAGEMENT OF THE ELECTROLYTIC RECTIFIER

The Solution.—The solution used in the Hickley rectifier is non-inflammable and does not contain acid.

In setting up the solution distilled water or rain water free from foreign matter and acids should invariably be used.

Evaporation and decomposition of the water of the solution should be taken care of by occasionally adding fresh water. The amount of water decomposed is proportional to the amount of current in watts passing through the solution.

When the solution has become "milky" in appearance and there is deposited a sediment in the bottom of the cell, the solution requires renewing. The sediment deposited contains small particles of aluminum which act as conductors and, consequently, reduce the efficiency of the cell.

The Electrodes.—The aluminum electrodes are made of a special alloy and are fitted with glazed porcelain tops. The formation of the hydroxide of aluminum takes from the electrode minute particles of aluminum, so that the greater the demand for current made upon the rectifier, the greater is the disintegration that takes place. The porcelain cap should be kept secure and tight, else the solution will creep under it and interfere with proper rectification, and allow the electrode and the solution to become quite hot. Electrodes should be suspended freely in the center of the jar and should not be permitted to touch the sides. The electrodes should not be handled any more than is absolutely necessary, as the hydroxide is liable to be destroyed by undue handling.

Installing and Starting.—The location of the rectifier should be a place where there is good air circulation. The cells should be supported on insulators as it is important that there should be no electrical contact between the rectifier and the ground, or between the cells. Owing to the possibility of the hydroxide coating being destroyed in shipping, it is well in setting up new cells to take the precaution to pass a small current through the rectifier for an hour or so before the entire load is thrown on. Should a rectifier for any reason be retired for an indefinite period, it is well to remove the electrodes and hang them in a dry place where they will be free from handling until required for service. If inspection of the rectifier should disclose cracks in the porcelain cap of an electrode, the electrode should be replaced immediately.

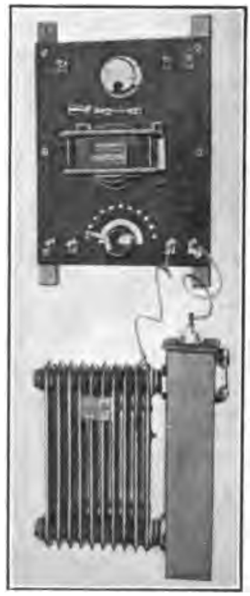


FIG. 39.—Electrolytic rectifier and switch panel.

The humming sound sometimes in evidence may be due to the operation of the transformer or the reactance, but should the sound increase in volume, it is probable that a defect has developed and that alternating current is passing through. The gases released by decomposition of the water in the solution escape through vent holes in the top of the cells. After long continued operation it may be found that the gases have carried upward particles of the chemicals from the solution, which on coming in contact with the air have formed crystals in and around the vent holes, thus interfering with the escape of the gases. Vent holes should be kept free of obstructions. Crystals which may have formed should be brushed back into the cell, where they will quickly dissolve. Fig. 39 is a reproduction of a photograph of a type *B* Hickley rectifier.

CHAPTER V

POWER-BOARD WIRING; BATTERY SWITCHING SYSTEMS AND ACCESSORIES

It is desirable that currents furnished by dynamos for the operation of telegraph circuits should be as nearly continuous as possible. By this is meant that the currents so supplied should closely resemble the non-pulsatory currents derived from primary batteries. The internal resistance of the gravity battery is about 2 1/2 ohms per cell, and this resistance in itself has the effect of controlling the current derived from a given number of cells. For instance, suppose a certain battery consists of 100 cells, each cell having an internal resistance of 2 1/2 ohms, and an e.m.f. of 1.07 volts; by Ohm's law it may be shown that on short circuit the current available from the battery will be 0.42 ampere, or about 420 milliamperes, for

$$\frac{1.07 \times 100}{2.5 \times 100} = 0.42 \text{ ampere.}$$

Machine generators of electricity, such as are employed to furnish telegraph currents, have a very low internal resistance; considerably less than an ohm. When these machines are employed in place of chemical batteries, it is customary to insert in the potential leads a total resistance which equals about 2 ohms per volt in order to protect the generators in case short circuits occur in the telegraph apparatus, or in event of grounds occurring on line wires at points close to the home office, and also for the purpose of controlling excessive "sparking" between the contact points of instruments, where circuits carrying comparatively large currents are opened and closed continuously.[1]

The purpose of the power-board is to provide convenient mounting for the various accessories which as a whole make up the battery switching system.

In most installations the power-board has mounted upon it the switches and fuses controlling the primary or motor circuits as well as those controlling the secondary or dynamo circuits. Other accessories usually mounted on the face of the board include ammeters, voltmeters, and field-regulating rheostats.

When the type of battery resistance unit employed consists of a coil of

[1] As explained in a later chapter, the present tendency of American telegraph engineering in this regard, is to reduce the amount of resistance inserted in the potential leads. A reduction of the number of ohms per volt of potential requires that dependence must be placed in fuses to protect the dynamo in the event of short circuits, and that improved means must be availed of to reduce the spark at "make" and "break" contacts.

"resistance" wire the various units are mounted on "coil racks," and when the type of resistance used consists of a form of incandescent lamp, the resistance units are mounted in "banks." Dynamo leads go directly from the power-board to the coil racks, or to the lamp banks, as the case may be.

The diagram, Fig. 40, shows the motor "supply" wires leading from the busbars, through the fuses in each side of the circuit, to a double-pole single-throw knife switch, the latter serving to close or open the circuit leading to the motor end of a dynamotor. The dynamo end is shown as having the negative terminal grounded. The positive terminal is connected through the power-board and "resistance" rack to its prearranged service assignment in the operating-room.

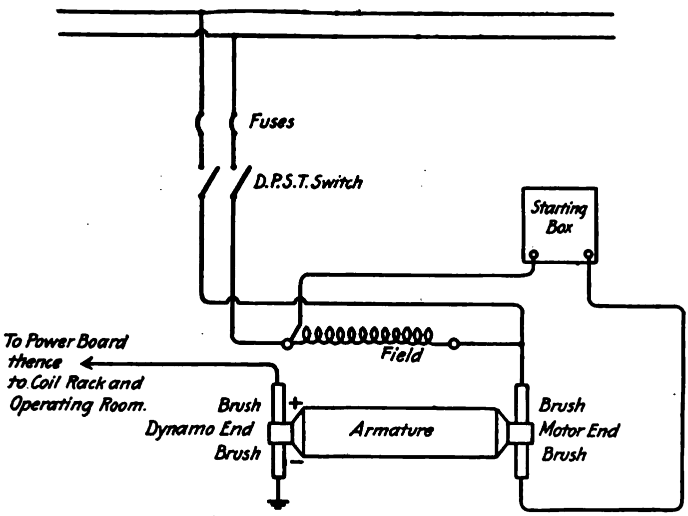


FIG. 40.—Dynamotor wiring connections.

The Postal Telegraph-Cable Company's dynamo arrangement provides that 40-volt potentials supply current for the operation of sounder circuits, repeater locals, duplex and quadruplex pole-changer and transmitter key circuits, lamp annunciator circuits, etc. For the operation of Morse short single circuits, loops, and for intermediate battery purposes 85-volt potentials are employed, while the longer main-line wires operated single Morse, are fed from 130-volt or 200-volt potentials. Machines supplying respectively 200 volts of each polarity (positive and negative) are allotted to duplex operation. Three hundred and eighty-five volts, positive and negative, respectively, are used for the operation of quadruplex circuits, and high-potential "leak" duplex circuits.

Forty-volt mains for use in local circuits are brought from the coil racks, before mentioned, to fuse-blocks situated on the tops of instrument tables

in the operating-room. Forty-volt, 85-volt, and 125-volt mains for application to single main lines are brought from coil racks to disks in the main-line switchboard (see Fig. 41) and properly marked, indicating potential and polarity. Two-hundred-volt and 385-volt "plus" and "minus" leads are brought directly from the power-board to cabinets located in the aisle ends of instrument tables, there connected through the proper resistance coils to six-point switches situated on the tops of the tables.

Figure 42 shows the wiring and battery connections of the type of six-point switch used for the purpose. Throwing the switch lever to the right places the lower or 200-volt potentials in connection with the "line" contacts

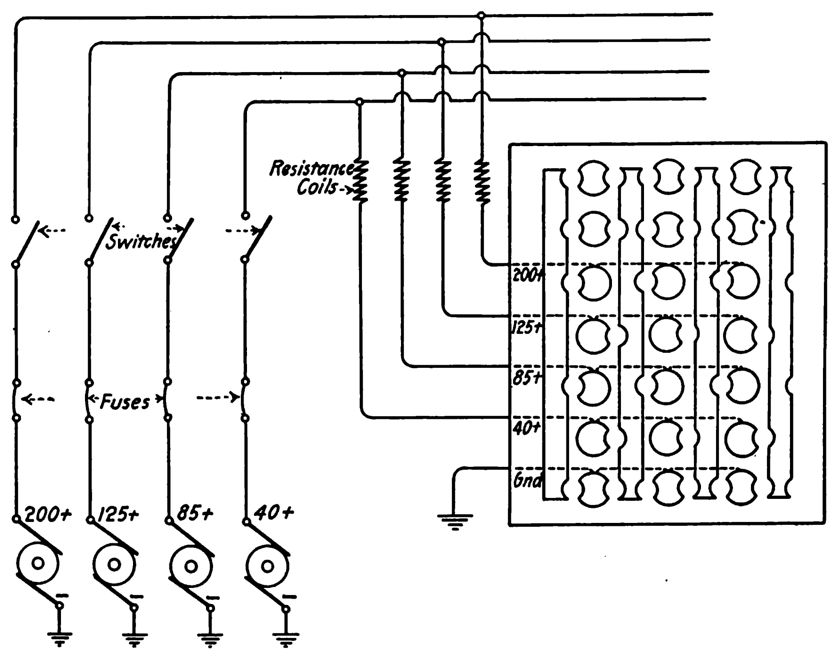


FIG. 41.—Potential mains connected to battery disks in main line switchboard.

of the multiplex apparatus, while throwing the lever to the left connects the higher, or 385-volt potentials with the line instruments.

In the newer offices the plan has been followed of carrying all battery wires leading from the power-board to the main switchboard and to instrument tables, in 2-in. iron piping. Where practicable the piping is imbedded in concrete flooring in the operating-room. Cast-iron hand-holes made from standard patterns are located at the aisle end of each table, the top of the hand-hole extending up into the wiring cabinet built into the end of the table. In this cabinet the various resistance coils and fuses are located.

The Western Union Telegraph Company's dynamo arrangement differs

only in detail from that just described. Owing to varying conditions in different localities, uniform battery arrangement has not always been possible. In some of the older Western Union installations, the arrangement referred to in the beginning of Chapter III is used, whereby a number of dynamos capable of generating like e.m.fs. are connected in series, each machine having a potential of, say, 60 volts. Six dynamos, each having an e.m.f. of 60 volts, if connected in series have an aggregate e.m.f. of 360 volts. A "tap" taken from the first machine of the series gives 60 volts, from the second 120

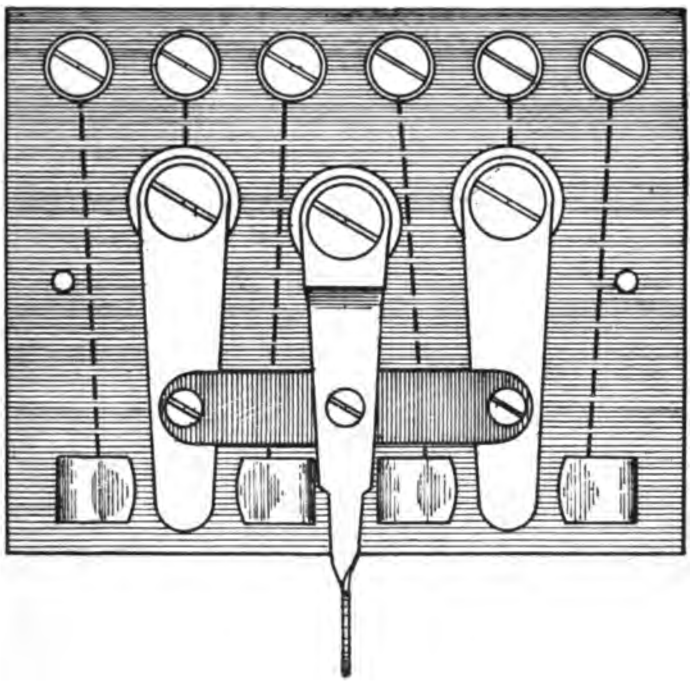


FIG. 42.—Six-point battery-switch for mounting upon operating tables.

volts, and so on in multiples of 60 volts until at the end terminal of the sixth machine an e.m.f. of 360 volts is available. As mentioned in Chapter III, with this arrangement it is necessary to provide a series of dynamos for each polarity, and to have available a third series as spare. In some installations multiples of 70 volts have been used in arranging a series of dynamos, and it is, of course, feasible to connect machines having different voltage outputs in a series, in order to meet particular requirements. The chief objection to the "series" arrangement is that in case an individual machine of a series becomes disabled, the entire series of which it forms a part has to be shut down until the disabled machine is repaired or replaced.

THREE-WIRE SYSTEM

Where conditions are such that a three-wire system of commercial power may be availed of to advantage, it is possible by means of power-board switching arrangements to obtain potentials of different values and of both polarities.

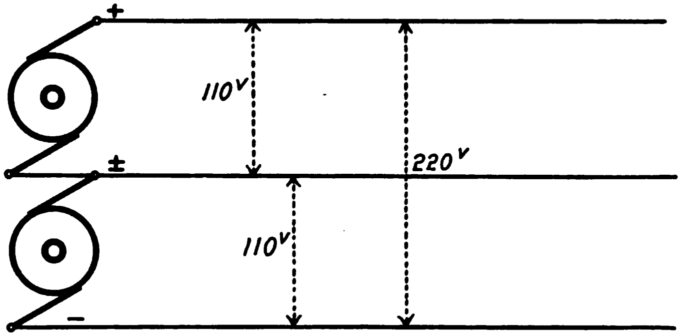


FIG. 43.—Three-wire system.

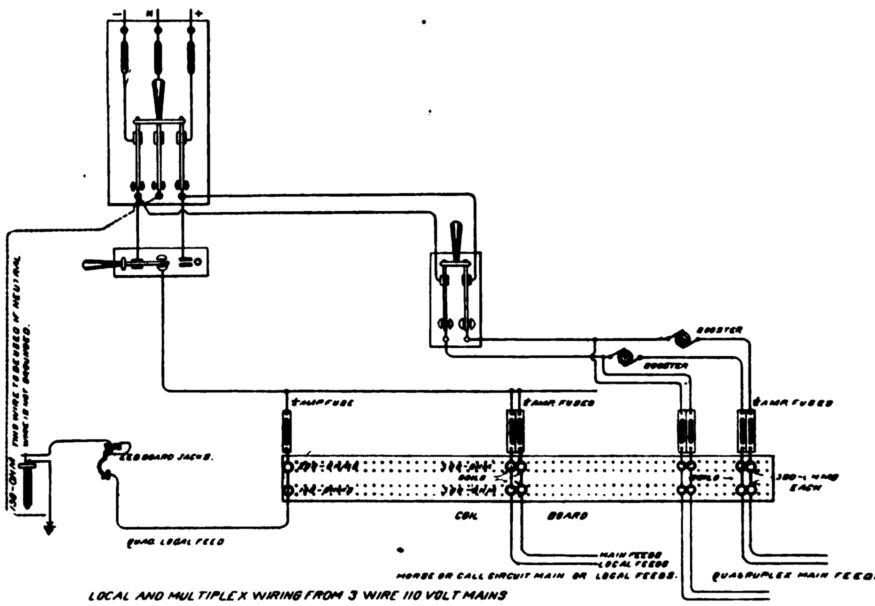


FIG. 44.

Fig. 43 shows diagrammatically the connections whereby two 110-volt generators are coupled together in some commercial power systems, for the purpose of avoiding the stringing of an out-going and a return conductor for each 110-volt generator. When two generators are coupled as indicated in the diagram,

one return wire serves for both machines. Also there is the additional advantage that while each generator external circuit is separate, for all practical purposes, it is possible to obtain from the two outside wires a potential of 220 volts —110 positive and 110 negative.

Figure 44 gives the connections usually made when the three-wire system is utilized for telegraphic purposes. By following the connections it may be seen that either the 110-volt positive or negative wire may be applied direct to quadruplex locals, main lines or call circuits, by way of the single-pole double-throw switch, 1/2-ampere fuses and regulation resistance coils; the latter mounted on coil racks previously referred to, while the fuses and the knife switch are mounted on the face of the power board.

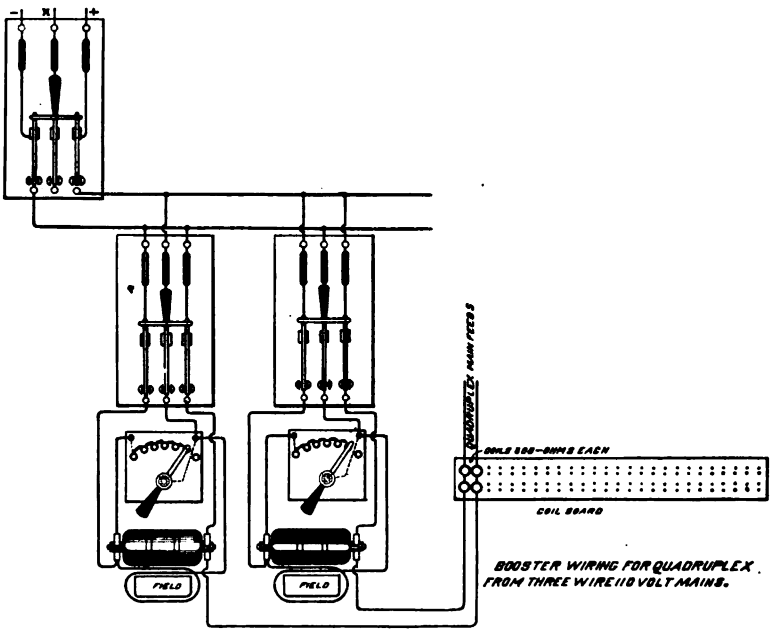


FIG. 45.

By connecting the two outside conductors of the three-wire service through the double-pole single-throw switch, fuses, and resistance coils, 110-volt potential is obtained for the operation of duplex circuits; that is, 110 volts of each polarity.

The double-pole single-throw switch also places the commercial 110-volt positive and negative leads, each in series with the generator terminals of "booster" motor-generators, thereby adding the voltage of the latter to that of the former. Boosters having out-puts of 130 volts positive and negative respectively and connected as shown in Fig. 44, raise the potentials to 240 volts for the operation of duplexes and short quadruplexes.

BOOSTER CONNECTIONS

Figure 45 shows the starting-box and "booster"[1] connections necessary to obtain quadruplex potentials of each polarity from three-wire mains.

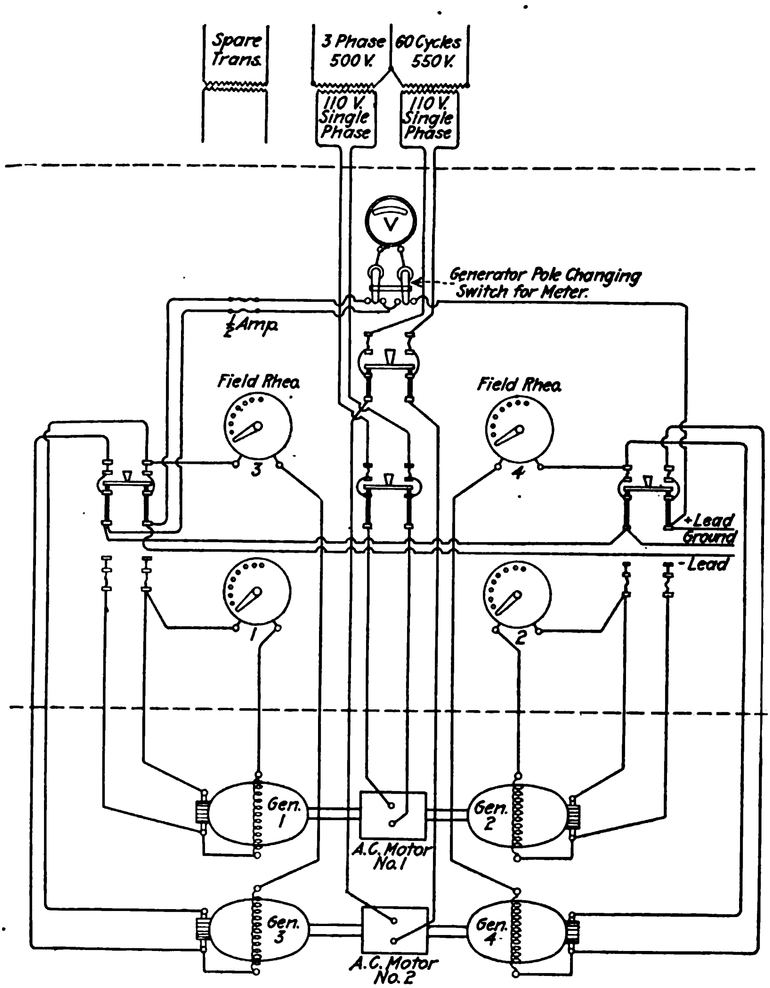


FIG. 46.—Typical power-board wiring.

[1] The "booster" consists of a generator driven by a motor mechanically connected to its armature shaft. The terminals of the generator are connected in series with one "leg" of the feed system. The current in the feed wire excites the field in proportion to the amount of current flowing. Inasmuch as the armature is independently rotated in the field, it will produce an e.m.f., in proportion to the excitation, and this e.m.f., is added to that of the feed system.

POWER-BOARD WIRING

Figure 46 shows the power-board wiring of an installation comprising two motor-dynamos with alternating-current primaries. The primary circuits from transformers through the double-pole single-throw switches to motors, and the secondary, or dynamo circuits through field-regulating rheostats and double-pole, double-throw switches to service mains are readily traceable.

Figure 47 shows the wiring of a power-board, embracing two panel-boards, switches, fuses and resistance units of a "rectifier" installation. The double-pole, single-throw switch shown in the upper right-hand corner serves to connect the alternating-current supply circuit with the electrolytic rectifier cells. The

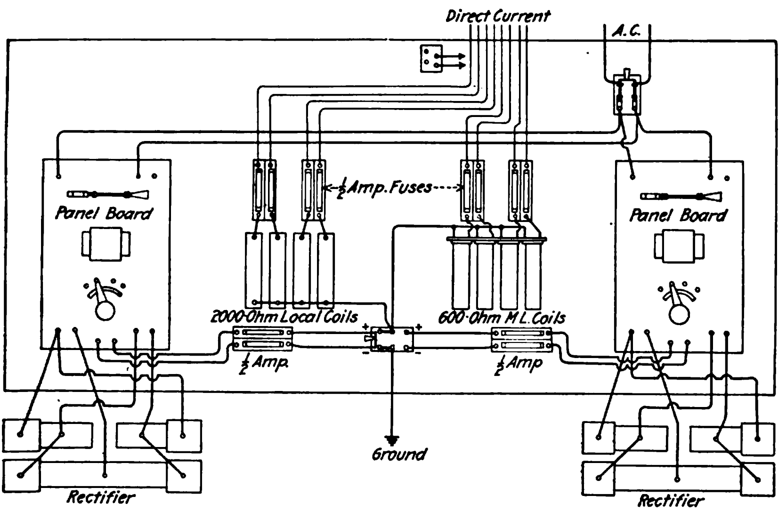


FIG. 47.—Power-board wiring of an electrolytic rectifier installation.

secondary, or direct current derived has the negative side grounded from the double-pole, double-throw switch shown in the center of the diagram, while the positive lead is connected through resistance coils and fuses to the desired service assignment.

Figure 48 shows a diagram of the wiring of a power-board installation which provides all necessary switching arrangements for a motor-generator plant consisting of:

8 motor generators with 110-volt primaries.
3 of them having 385-volt secondaries.
3 200-volt secondaries.
1 50-volt secondary.
1 150-volt alternating-current secondary (for phantoplex service).

The diagram shows the switch terminal connections, busbar and ground con-

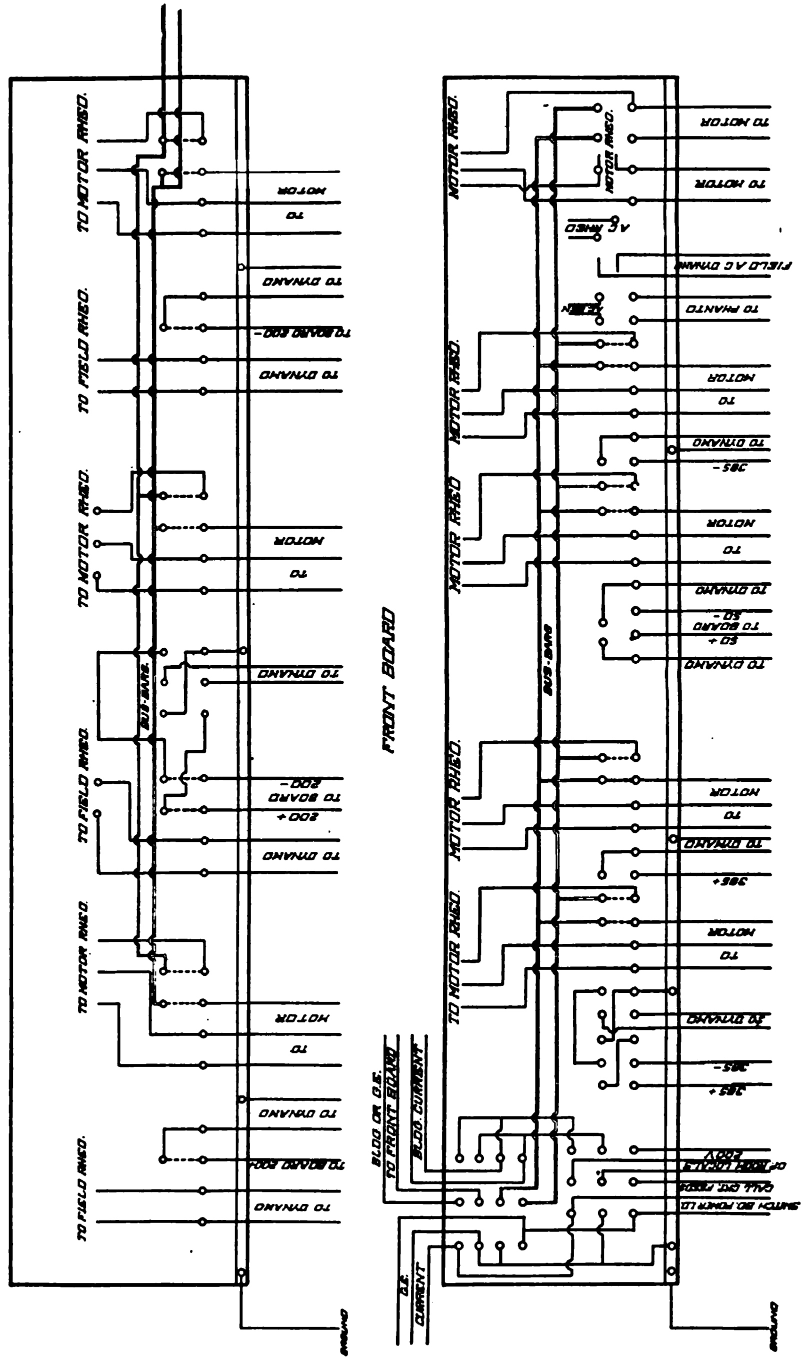


FIG. 48.—Bus-bar and knife-switch connections of a large telegraph power-board.

nections necessary to control the various motor circuits; also the potential leads from the dynamo ends of the various units, which latter are carried to the desired service assignment in the operating-room via the resistance coil racks.

In this particular installation the current employed to operate single lines and local circuits is derived from the regular commercial 110-volt service, thus obviating the employment of motor-generators to supply current for such purposes.

Where 110-volt current is used for the operation of "local" circuits, 2,000-ohm resistance coils are inserted in series with the mains, and the local instru-

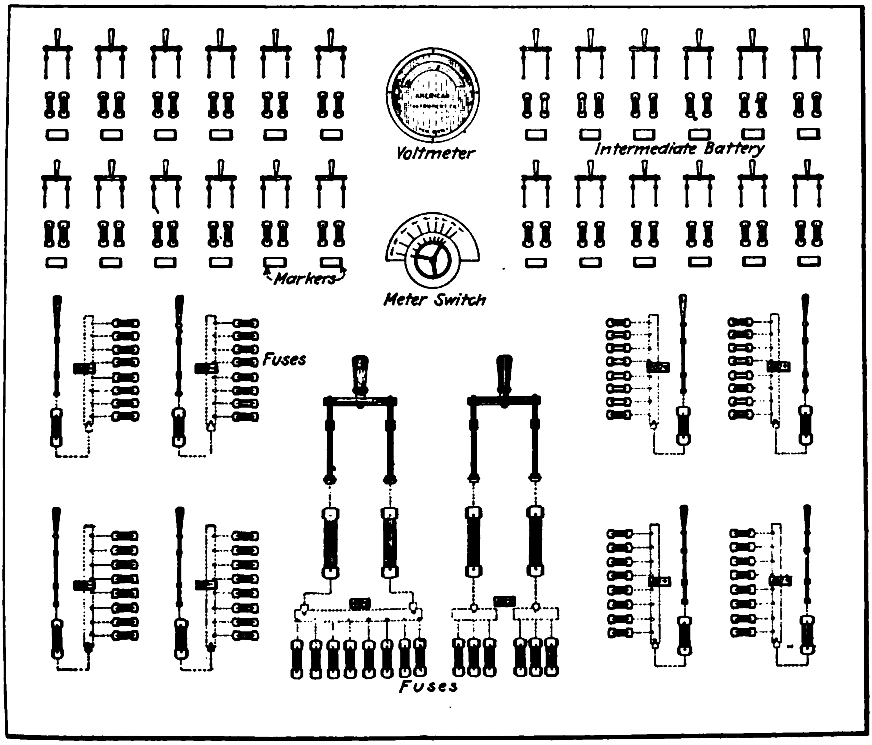


FIG. 49.—Auxiliary power-board, knife-switch and fuse arrangement.

ments; such as sounders, transmitters, pole-changers, repeaters, call-circuit relays, etc., are wound to a resistance of 150 ohms each.

The potential mains leading from the power-board to the operating-room are carried in iron pipe 1 1/2 in. in diameter, the conductors for the high voltage consist of No. 6 B. & S., copper, rubber insulated and lead covered. For the lower voltages the conductors consist of No. 12 B. & S. copper, rubber insulated twin-conductor, lead covered.

Where a twin-conductor cable is used to carry dynamo currents from the power-board to the operating-room, it is customary so to divide the circuits that two "plus" leads or two "minus" leads are carried in one cable. This method of current distribution subjects the insulation of the conductors to considerably less disruptive strain than when opposing polarities are carried in the same cable. In some of the larger telegraph offices, the motor-generator equipment is located in the basement of the building, or in a location remote from the operating-room. Control of the machinery by the dynamo attendant necessitates that the power-board be located close to the machines. A very convenient provision, and one which at the present time, is considered good

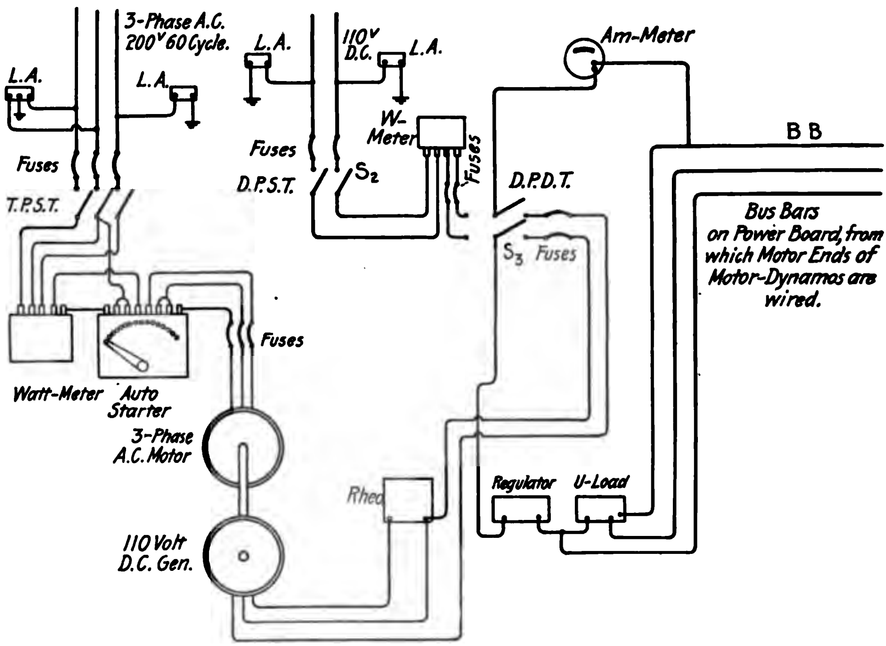


FIG. 50.—Typical power-board installation.

practice, is to have in the operating-room, or in a smaller room on the same floor in close proximity thereto, an auxiliary power-board to which are connected all potential mains from the power-board proper. This arrangement gives the operating-room attendants direct control over current distribution, and is of considerable utility in the matter of making alterations in battery assignments.

The equipment of such an auxiliary-board is depicted in Fig. 49. At the top in the center is shown a voltmeter, and underneath it, a meter-switch common to all potential leads. By moving the indicator of the switch opposite the marker of the voltage and polarity intended to be measured, the voltmeter circuit is completed from the desired potential conductor to ground.

The double-pole single-throw, and the single-pole single-throw switches have "marker" cards mounted near them which indicate the voltage and polarity of each terminal. In the case of mains having one polarity only (controlled by the S. P. S. T. switches) it may be noted that the circuit extends from the full-load fuse at the bottom of the switch to a small "bus" to which eight service conductors are connected through individual fuses.

Figure 50 shows the external connections of a typical installation where both 110-volt direct-current and 200-volt alternating-current commercial voltages are available for the purpose of operating motor-generators. On the left, the 200-volt alternating-current supply wires are shown connected through line fuses, three-pole single-throw switch, wattmeter, and auto-starter to the motor terminals. A direct-current generator with an output of 110 volts, directly connected to and driven by the alternating-current motor has its voltage impressed on the busbars *B–B* when the switch S_3 is thrown to the right. The external connections of the generator field rheostat, current regulator, and under-load automatic circuit-breaker are shown in proper order. (The internal connections of these various current-controlling devices are described in detail in Chapter III.) The eight or more motor-generators or dynamotors usually required to operate the different telegraph circuits derive their motor operating current from the busbars *B–B*. The connections made between busbars and motor ends of motor-generators may be traced by aid of diagrams 25, 26 and 27.

In the installation illustrated in Fig. 50, the motor-generators connected to the busbars may be operated either from the 110-volt current generated on the ground as above described, or may be operated from the 110-volt "street" mains. In the latter case the switch S_2 is closed, and the switch S_3 is thrown to the left.

CHAPTER VI

CIRCUITS AND CONDUCTORS; THE ELECTRIC CIRCUIT; THE MAGNETIC CIRCUIT; ELECTROMAGNETS

The general statement of Ohm's law given under the heading of "Units and Symbols" in Chapter I provides a means whereby the properties or characteristics of electric circuits may be investigated.

An electric circuit such as that illustrated in Fig. 51, possesses capacity, resistance, and inductance. Also as the circuit has an e.m.f. applied to it, there is potential and current to reckon with. In the order given the symbols representing these various factors are:

Capacity,	"C"	(farads)
Resistance,	"R"	(ohms)
Inductance,	(h)	(henries)
E.M.F.,	(E)	(volts)
Current,	(I)	(amperes)

In what follows, where diagrams accompany descriptions of different circuit arrangements, sources of e.m.f. will be represented as in Fig. 51. It is to be understood, however, that so long as we are dealing with direct currents, the method employed to produce the difference of potential is immaterial, and the circuit depicted in Fig. 51 might be shown as in Fig. 52, where a direct-current dynamo is the source of e.m.f.

An electric circuit, so called, consists of a path composed of a conducting wire, or of several wires connected together, through which an electric current is said to flow from a given point; along the conducting path and back to the starting-point (Fig. 53).

A circuit which may be "opened" or "closed" at will has connected in its conducting path a "key" or "switch" as illustrated in Fig. 54.

A circuit is said to be "open" when its conducting path is broken, or otherwise disconnected, and "closed" when the conducting path is complete, permitting electrical action to take place.

A "grounded" circuit is one such as that illustrated in Fig. 55, where both terminals of the source of e.m.f. are grounded.

When a circuit is divided into two or more parts, it is called a "divided" circuit, and each part will carry a portion of the current, see Fig. 56.

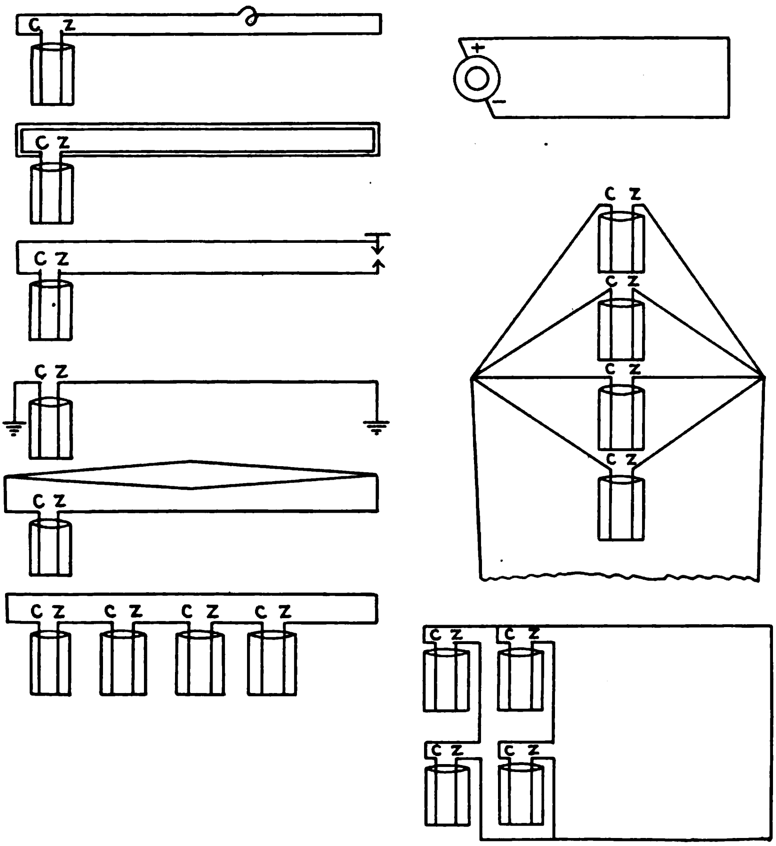
Voltage, resistance, and current values in electric circuits may be deter-

mined by means of Ohm's law, by employing the formulæ evolved from the statement of principles before referred to. In their shortest form these are:

$$I=\frac{E}{R}$$

$$R=\frac{E}{I}$$

$$E=I\times R.$$



51 52 53 54 55 56 57 58 59

FIGS. 51–59.

Unit sources of e.m.f. may be arranged in different ways in order to obtain desired results. The various arrangements outlined in the diagrams which follow, apply equally to dynamos, chemical batteries, and to other sources of continuous currents.

Where chemical batteries are employed for practical purposes, their comparatively high internal resistance per cell; in certain applications makes it desirable to so arrange the elements of a battery that the internal resistance

of the battery as a whole is less than the sum of the individual resistances of all of the cells comprising the battery.

In Fig. 57 the positive and negative elements of each cell are connected in "series." It is apparent that the circuit is made up of the conducting wire, positive and negative elements of each cell, and the electrolyte intervening between the elements of each cell. Therefore, the current produced by an individual cell in traversing the circuit is required to pass through one after the other of the cells of the battery.

If we consider that the battery shown in Fig. 57 consists of gravity cells, each having an e.m.f. of 1.07 volts and an internal resistance of 2.5 ohms, and that the "external" circuit or conducting wire has a resistance of 10 ohms it is possible by means of the formula

$$I=\frac{E}{R}$$

to calculate the value of the current in amperes, flowing in the circuit; thus:

$$E=1.07\times 4=4.28 \text{ volts.}$$
$$R=10+(2.5\times 4)=20 \text{ ohms.}$$

and

$$\frac{4.28}{20}=0.214 \text{ ampere, or } 214 \text{ milliamperes.}$$

The e.m.f. of a cell is independent of the size of the elements constituting the cell (the copper and the zinc electrodes). This means that a cell the size of a tea cup has the same e.m.f. as a cell of the regulation size or larger. The internal resistance, however, differs considerably. Also, the life of the cell and the current that may be derived in each case makes the larger size of greater utility.

In the arrangement shown in Fig. 57, the cells are connected so that the greatest quantity of current is obtainable where the external circuit has a comparatively high resistance.

In the arrangement shown in Fig. 58 the cells are connected in "multiple," that is, all of the positive electrodes are connected together and all of the negative electrodes are likewise joined, thus in effect making one large cell in which all of the zincs constitute one element and all of the coppers the other element. This arrangement produces the largest quantity of current through an external circuit of comparatively low resistance. Assuming that each cell has an e.m.f. of 1.07 volts, the total e.m.f. of the four cells arranged in series (Fig. 57) will be 4.28 volts, while the voltage derived from the multiple arrangement (Fig. 58) will be, simply the voltage of one cell, or 1.07 volts. In each case, however, the total internal resistance will differ, as in the series arrangement the resistance of each cell (2.5 ohms) is added to that of the others, making a total resistance of 10 ohms, while the total internal resistance of

the four cells arranged in multiple, due to quadrupling the size of the plates, or elements, would be but a fraction of an ohm, as will be explained in connection with calculations pertaining to the resistance of joint circuits.

Figure 59 shows a multiple-series arrangement of cells in which two groups of two cells each in series are connected to the external circuit in multiple. In this case the derived e.m.f. would be $1.07+1.07=2.14$ volts, and the total resistance of the battery 2 1/2 ohms.

The total voltage of a battery is dependent upon the number of cells in "series." If it is desired to obtain a greater current in amperes from a battery, without changing the e.m.f. (voltage) additional cells must be placed in parallel or multiple, as shown in Fig. 58. Consider for instance, that a given battery arranged as shown in Fig. 57 has 100 cells instead of four as there illustrated. At the terminals of the battery there will be a total e.m.f. of

$$1.07 \times 100 = 107 \text{ volts.}$$

If, then it is desired to increase the "current" without increasing the "voltage" an additional series of cells may be connected in parallel to the first series, thus adding its current to the circuit without increasing the e.m.f. of the battery as a whole. Additional rows of cells in series may be added as indicated in Fig. 58, where four rows of one cell in series are connected in parallel. This battery would be referred to as having one cell in series and four cells in parallel.

By means of simple formulæ, the current obtainable from a battery connected in a given manner may be calculated with sufficient accuracy for all practical purposes.

Let E = e.m.f. of one cell,
r = Internal resistance of one cell,
R = External resistance of the circuit, if any.

Then for n cells connected in series, the current in the circuit will be represented by the formula:

$$I=\frac{nE}{nr+R}$$

With one cell on short circuit and no appreciable external resistance, the current is:

$$I=\frac{E}{r}$$

In the case of long telegraph circuits where nr is small as compared with R, the current obviously increases in proportion to the number of cells employed, and:

$$I=\frac{nE}{R+(rn)}$$

The value of r is approximately inversely proportional to the area of the plates separated by the electrolyte and directly proportional to their distance apart, therefore, if the total area of the positive and the negative electrodes is increased by connecting cells in parallel, the general application of the formula is:

$$I=\frac{E}{\frac{r}{a}+R}=\frac{aE}{r+aR}$$

where the area of the plates of one cell is increased a times.
Now, if N = the total number of cells in the battery,

n = the number of cells in series,
P = the number of rows in parallel,

then the internal resistance of the battery

$$=\frac{nr}{P}$$

To so arrange cells that the maximum current may be obtained in a given external circuit, make

$\frac{nr}{P}$ equal to the resistance of the external circuit

In any given circuit

$I=\frac{\text{total e.m.f.}}{\text{total resistance,}}$ and for any given arrangement

of cells

$$I=\frac{nE}{\frac{nr}{P}+R}=\frac{PnE}{nr+PR}$$

To determine the maximum current in amperes obtainable from a given battery having N cells, through an external circuit of resistance R

$$I=\frac{E}{2}\sqrt{\frac{N}{Rr}}$$

In practice the cells of a battery may be connected in three different ways, (1) all cells in series, (2) all cells in parallel, (3) some cells in parallel, and some in series.

If n represents the number of cells in series and P the number of cells in parallel; obviously the total number of cells in the battery equals the product of n and P, or $n \times P$.

The c.m.f. of a battery equals the e.m.f. of one cell multiplied by the number of cells in series.

The resistance in ohms, of a battery equals the number of cells in series multiplied by the resistance of one cell, divided by the number of cells in multiple, or parallel. For example, a battery of 48 cells, each having an e.m.f., of 1.07 volts and an internal resistance of 2 1/2 ohms, connected in series, has a total resistance

$$r=2.5\times 48=120 \text{ ohms.}$$

And an e.m.f.

$$E=1.07\times 48=51.36 \text{ volts.}$$

The same battery with all cells connected in parallel would have

$$r=\frac{1\times 2\ 1/2}{48}=(0.052) \text{ ohms,}$$

and

$$E=1.07\times 1=1.07 \text{ volts.}$$

A battery of 50 cells arranged in ten rows of 5 in series (see Fig. 59) would have

$$r=\frac{5\times 2.5}{10}=1.25 \text{ ohms}$$

$$E=5\times 1.07=5.35 \text{ volts.}$$

A typical example of actual telegraphic practice would be to find the number of cells of gravity battery required to furnish a current of 45 milliamperes (0.045 ampere) in a circuit having a conductor resistance of 800 ohms, and a total instrument resistance of 600 ohms. Taking the e.m.f. per cell to be 1.07 volts, and the internal resistance per cell as 2 1/2 ohms, we have

N = the number of cells required,
R = the total external resistance,
r = the internal resistance per cell,
E = the e.m.f. per cell,
I = the current required in the circuit.

Then

$$N=\frac{R}{\frac{E}{I}-r}=\frac{1,400}{\frac{1.07}{0.045}-2\ 1/2}=65 \text{ cells}$$

Where the resulting figures contain a fraction, the nearest whole number may

be taken as the practical requirement. The result obtained in the last example may be "proved" by means of Ohm's law,

$$I = \frac{E}{R}, \text{ as in this case,}$$

$$E = 65 \times 1.07 = 69.55 \text{ volts,}$$
$$R = 800 + 600 + 162.5 = 1{,}562.5 \text{ ohms,}$$

and

$$\frac{69.55}{1562.5} = 0.44+ \text{ ampere, or 45 milliamperes,}$$

thus checking the original calculation and proving that the determination was correct.

The resistance of telegraph lines invariably is considerably greater than the internal resistance of the battery employed, and as stated in connection with Fig. 57, the cells are arranged in series. Occasionally, however, a condition arises where an external circuit having comparatively low resistance has to be supplied with a current somewhat greater than that required in ordinary telegraph work, and where such requirements have to be met by suitable primary battery arrangements, the parallel or series-parallel coupling of cells may be used to advantage.

Conductor Resistance.—The resistance of a conducting wire is proportional to its length. If the resistance of a mile of copper telegraph wire is 10 ohms, that of 100 miles of the same wire will be $10 \times 100 = 1{,}000$ ohms.

The resistance of any given conductor is inversely proportional to the area of its cross-section, and in the case of round wires, is inversely proportional to the square of the diameter of the conductor. A No. 9 copper wire (B. & S. gage) having a diameter of 0.114 in. has a resistance of 4.39 ohms per mile at a temperature of 75° F. A wire having twice that diameter or 0.228 in. would have a resistance but one-fourth that of the former.

The resistance with which a conducting wire of given length and given cross-sectional area opposes the passage of a current of electricity, depends upon the material of which the conducting wire is made or, in other words, depends upon the specific resistance of the material.

Let R represent the resistance of the conductor in ohms,

ρ represent specific resistance of the conductor,
A represent cross-section of the conductor,
l represent length of the conductor.

Then $$R = \rho \frac{l}{A}$$

or $$\rho = R \frac{A}{l}$$

If the length (l) is measured in inches, and the cross-section (A) in square inches, then ρ is the resistance of an inch cube of the conductor.

In telegraph practice it is customary to refer to specific resistance in terms of the mile-ohm, which signifies the weight in pounds of a conductor having a length of 1 mile and a resistance of 1 ohm.

In those instances where specific resistance is referred to in terms of ohms per mil-foot (the resistance of a round wire 1 ft. long and 0.001 in. in diameter) length (l) is measured in feet, and area (A) in circular mils. If the length (l) of a conductor is measured in centimeters and the area (A) in square centimeters ρ is the resistance of a centimeter cube of that conductor.

The term conductance is used as the inverse of resistance. A conducting wire whose resistance is R ohms is said to have a conductance of

$$\frac{1}{R}\text{ ohms}$$

Specific conductivity is the reciprocal of specific resistance, and if γ represents specific conductivity,

$$\gamma = \frac{l}{\gamma A}$$

$$\gamma = \frac{l}{RA}, \text{ and } \gamma = \frac{l}{\rho}$$

CONVERSION FACTORS

1 mil = 0.0254 mm. = 0.001 in.
1 mm. = 39.37 mils = 0.03937 in.
1 cm. = 0.3937 in. = 0.328 ft.
1 in. = 25.4 mm. = 0.083 ft. = 2.54 cm.
1 circular mil = 0.7854 sq. mil = 0.0005067 sq. mm.
1 sq. mil = 1.273 cir. mils = 0.000645 sq. mm. = 0.000001 sq. in.
1 sq. mm. = 1,973 cir. mils = 1,550 sq. mil = 0.00155 sq. in.
1 sq. cm. = 197,300 cir. mils = 0.155 sq. in. = 0.00108 sq. ft.
1 sq. in. = 1,273,240 cir. mils = 6.451 sq. cm. = 0.0069 sq. ft.
1 cir. mil-foot = 0.0000094248 cu. in.
1 cu. cm. = 0.061 cu. in.
1 cu. in. = 16.39 cu. cm.
The microhm = 0.0000001 ohm.
Microhms per inch cube = 0.3937 × microhms per centimeter cube.
Pounds per mile-ohm = 57.07 × microhms per cm. cu. × specific gravity.
Ohms per mil-foot = 6.015 × microhms per cm. cu.

The square of the diameter of a given wire expressed in mils (0.001 in.) gives the circular mils.

Problems involving comparisons of conductors having unequal resistances, require that:

The square of the diameter of each wire be multiplied by the length of the other. The ratio of the resistance of one wire to that of the other is obtained by dividing the products thus obtained. The resistance value sought is determined by multiplying the ratio by the known resistance.

For example:

A given wire of 50 mils diameter and 20 miles long has a resistance of 200 ohms. Another wire has a diameter of 40 mils and is 40 miles long. Assuming that the wires are made of the same material what is the resistance of the second wire?

Solution:

$50^2 \times 40 = 100{,}000$, relative resistance of first wire.
$40^2 \times 20 = 32{,}000$, relative resistance of second wire.

$\frac{100{,}000}{32{,}000} = 3.125$, ratio of second wire to the first.

and

$200 \times 3.125 = 625$ ohms.

As an example of calculating the required diameter in mils of a conducting wire, assume that a wire 1 mile (5,280 ft.) long has a diameter of 100 mils and a resistance of 10 ohms; what would be the diameter of a wire made of the same material of which a length of 1 mile has a resistance of 40 ohms?

Solution:

$\frac{40}{10} = 4$ (ratio of resistances)

$\frac{5{,}280}{4} = 1{,}320$ ft.

and

$\frac{1{,}320 \times 100^2}{5{,}280} = 2{,}500$, which is the square of the diameter of the second wire,

and

$\sqrt{2{,}500} = 50$ (mils)

SPECIFIC RESISTANCE, RELATIVE RESISTANCE, AND RELATIVE CONDUCTIVITY OF CONDUCTORS
Pertaining to Mathiessen's standard

Metals	Resistance in microhms at 0° C. Centimeter cube	Resistance in microhms at 0° C. Inch cube	Relative resistance, per cent.	Relative conductivity, per cent.
Silver, annealed	1.47	0.579	92.5	108.2
Copper, annealed	1.55	0.610	97.5	102.6
Copper (Matthiessen's standard)	1.594	0.6276	100	100.0
Gold (99.9 per cent. pure)	2.20	0.865	138	72.5
Aluminum (99 per cent. pure)	2.56	1.01	161	62.1
Zinc	5.75	2.26	362	27.6
Platinum, annealed	8.98	3.53	565	17.7
Iron	9.07	3.57	570	17.6
Nickel	12.3	4.85	778	12.9
Tin	13.1	5.16	828	12.1
Lead	20.4	8.04	1,280	7.82
Antimony	35.2	13.9	2,210	4.53
Mercury	94.3	37.1	5,930	1.69
Bismuth	130.0	51.2	8,220	1.22
Carbon, (arc light)	4,000.0	1,590 (appr.)	....	....

At 18° C. pure water has a resistance of 2,650 ohms per cm.cu., and 1,050 ohms per inch cube. The following example will illustrate the value of the above table in connection with the formula given on page 77. According to the table the specific resistance of iron is 3.57 microhms per cubic inch, this is equal to 0.00000357 ohms. Required the resistance of a wire 100 ft. long and 0.010 in. in diameter. By employing the formula

$$R=\rho\frac{l}{A}$$

we have $\rho=0.00000357$

$$A=\frac{\pi d^2}{4}=\frac{3.1416\times .010^2}{4}=0.00007854 \text{ sq. in.}$$

and $l=100 \text{ ft.}=1,200 \text{ in.}$

$$R=\frac{0.00000357\times 12}{0.00007854}=0.55 \text{ ohm.}$$

The commercial standard of conductivity (Mattheissen's) is a copper wire having the following properties at a temperature of 0° C.

Relative conductivity	100 per cent.
Length	1 meter.
Weight	1 grm.
Specific gravity	8.89.
Resistance	0.141729 ohms.
Specific resistance	1.594 microhms per cm. cu.

Resistance Affected by Heating.—Changes of temperature affect the conducting properties of metals. Most of the pure metals increase in resistance approximately 0.4 per cent. for a rise in temperature of 1° C. German silver wire which is used in making resistance coils for telegraph purposes has a temperature coefficient of only about 1/10 that of pure metals, or 0.00044 for 1° C.

TEMPERATURE COEFFICIENTS

Let R_1 represent the resistance at 0°,
R_2 represent the resistance at $t°$,
a represent the temperature coefficient of the material,

then $R_2 = R_1\ (1+at)$.
100 a is the percentage of change in resistance per degree change in temperature. Where the resistance of the material at the higher temperature is known, the resistance of the same material at a lower temperature may be determined by means of the formula:

$$R_1 = \frac{R_2}{1+at}.$$

The following values of the temperature coefficients of various metals have been determined in degrees Centigrade and Fahrenheit.

Pure metals	Centigrade a	Fahrenheit a
Silver, annealed	0.00400	0.00222
Copper, annealed	0.00428	0.00242
Gold (99.9 per cent.)	0.00377	0.00210
Aluminum, (99 per cent.)	0.00423	0.00235
Zinc	0.00406	0.00226
Platinum, annealed	0.00247	0.00137
Iron	0.00625	0.00347
Nickel	0.00620	0.00345
Tin	0.00440	0.00245
Lead	0.00411	0.00228
Antimony	0.00389	0.00216
Mercury	0.00072	0.00044
Bismuth	0.00354	0.00197

It is important when calculating the resistance of a given material, noted at different temperatures, to use the temperature coefficient based on the "scale" (Fahrenheit or Centigrade) which was employed in recording the difference in temperature.

Example:

The resistance of a length of copper wire at 72° F. is 110 ohms. What would be its resistance at a temperature of 100° F.?

Solution:

$$R_1 = 110,$$
$$t = 100 - 72 = 28,$$
$$a = 0.00242,$$

and, substituting, we have:

$$R_2 = 110\ (1 + 0.00242 \times 28)$$
$$= 110 \times 1.06770,$$
$$= 117 \text{ ohms (approx.)}.$$

The following table gives the resistance of sizes 0000 to 40, American, or Brown and Sharpe (B. & S.) gage, of pure copper wire at a specific gravity (sp. gr.) of 8.9, and at a temperature of 75° F. (23.8° C.). Sixty degrees Fahrenheit, or 15.5° C. is the standard temperature for measuring the electrical resistance of wire for general telegraphic purposes, as that value is assumed to be the average temperature of air.

DIMENSIONS AND RESISTANCE OF PURE COPPER WIRE

(Specific gravity 8.9; resistance at 75° F.)

American or B. & S. gage	Diameter d in mils. 1 mil =.001 in.	Circular mils (d_2)	Pounds per 1,000 ft.	Feet per pound	R ohms per 1,000 ft.
0000	460.0	211,600	639.	1.56	.05
000	409.6	167,805	507.	1.97	.06
00	364.8	133,079	402.	2.49	.08
0	324.9	105,592	319.	3.13	.10
1	289.3	83,694	253.	3.95	.12
2	257.6	66,373	200.	5.0	.16
3	229.4	52,634	159.	6.3	.20
4	204.3	41,742	126.	7.9	.25
5	181.9	33,102	100.	10.0	.31
6	162.0	26,250	79.	12.6	.40
7	144.3	20,816	63.	15.9	.50
8	128.5	16,509	50.	20.	.63
9	114.4	13,094	40.	25.	.79
10	101.9	10,381	31.	32.	1.
11	90.7	8,234	25.	40.	1.26
12	80.8	6,530	20.	50.	1.59
13	72.0	5,178	15.6	64.	2.00
14	64.1	4,107	12.4	81.	2.53

DIMENSIONS AND RESISTANCE OF PURE COPPER WIRE—(*Continued*)

(Specific gravity 8.9; resistance at 75° F.)

American or B. & S. gage	Diameter d in mils. 1 mil = .001 in.	Circular mils d_2)	Pounds per 1,000 ft.	Feet per pound	R ohms per 1,000 ft.
15	57.1	3,257	9.8	102.	3.2
16	50.8	2,583	7.8	128.	4.0
17	45.3	2,048	6.2	161.	5.
18	40.3	1,624	4.9	204.	6.4
19	35.4	1,252	3.78	264.	8.0
20	32.0	1,021	3.09	324.	10.2
21	28.5	810	2.45	408.	12.8
22	25.3	643	1.94	515.	16.2
23	22.6	509	1.54	650.	20.4
24	20.1	404	1.22	819.	25.7
25	17.9	320	.97	1,033.	32.4
26	15.9	254	.77	1,302.	40.8
27	14.2	201	.61	1,642.	51.5
28	12.6	160	.48	2,071.	64.
29	11.3	127	.38	2,611.	82.
30	10.0	100	.30	3,294.	103.
31	8.9	80	.24	4,152.	129.
32	7.9	63	.19	5,237.	164.
33	7.1	50	.15	6,603.	207.
34	6.3	40	.12	8,328.	261.
35	5.6	32	.10	10,500.	329.
36	5.0	25	.08	13,240.	415.
37	4.5	20	.06	16,691.	524.
38	4.0	16	.05	20,850.	660.
39	3.5	12	.04	26,300.	832.
40	3.1	10	.03	33,200.	1,050.

From the foregoing it is evident that conductor resistance depends upon dimension, composition, and temperature of the conductor.

So far as external conductors in aerial lines and cables are concerned the average difference in temperature between summer and winter months, say 100° F. and 22° F., results in an increase of resistance while the higher temperature prevails, of about 26 per cent. for iron wire, and 18 per cent. for copper wire.

Where the windings of resistance coils and of electromagnets are involved the temperature of the conducting wire, or rather the variation in the temperature of the wire is always a factor to be reckoned with. The use to which resistance coils are put is such that frequently the temperature of individual coils may rise above 150° F. or 65° above normal (75° F. or 23.8° C.).

Joint-resistance.—Referring to Fig. 60, where a source of e.m.f. has both of its terminals joined by two conducting wires. If the several conducting

wires are of equal length and cross-section, composed of the same material and at equal temperatures, the current will divide equally between the two, and the electrical resistance of the joint-path will be the same as if there were but one conductor of the same length and of a cross-section equal to the total of the cross-sections of the two individual conductors. The current, therefore, existing in each conducting wire is in the same proportion to the total current circulating as the sectional area of one branch is to the total sectional area of the joint-path.

It is obvious that when a circuit is divided into two or more branches, variations in the characteristics of the individual conductors of the joint circuit, determine the amount of current flowing in each branch. Thus, one of the branches may be of greater length than the others, or the cross-sectional area of one may be greater than that of the others, or there may be involved a difference of temperature sufficient to increase or decrease the resistance of one of the conductors as compared with the electrical resistance of another of the conductors of equal dimension and of the same composition.

A derived or branch circuit is in effect a shunt circuit, see Fig. 61.

In a case such as that illustrated in Fig. 61, it is evident that the current

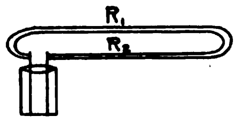


FIG. 60.

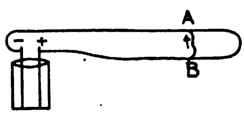


FIG. 61.

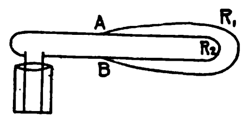


FIG. 62.

from the battery is shunted by the wire A–B, and, if we assume that the composition and dimensions of the wire in the longer loop and in the shorter circuit are identical, it is obvious that a greater portion of the total current circulating will exist in the shorter path. There are definite laws for determining the resistance values of shunt circuits, where it is desired by this means to regulate the amount of current flowing in circuits in which a shunt path forms a part of the joint circuit. These laws shall be considered presently.

There exists a popular fallacy in regard to the circulation of electric currents, which in the minds of those not familiar with electrical laws causes confusion, that is "that a current of electricity always takes the path of least resistance." The truth is that the major portion of the current flowing traverses the path of least resistance, but the current as a whole divides between the various paths in proportion to their electrical resistances individually. The relative strengths of current flowing in two branches of a circuit (Fig. 60) is inversely proportional to their resistances, and on the other hand, proportional to their conductances.

If the resistance of R_1 in Fig. 60 is 20 ohms, and R_2, 30 ohms,then the portion of the total current flowing in R_1 will be "as 20 is to 30," or, three-fifths of the total current will flow through R_1 and two-fifths through R_2.

In Fig. 62 the joint resistance of the divided circuit between *A* and *B* will be less than the individual resistance of either branch, as, through this portion of the circuit the current has a joint path equaling in sectional area the sum of the sectional areas of each conductor taken singly. The joint-conductance will be the sum of the two individual conductances. The statement of a law by means of which the joint-resistance may be determined is:

The joint-resistance of a divided conductor is equal to the product of the two separate resistances, divided by their sum.

In general, this is referred to as the Law of shunts.

In Fig. 62 if the branch R_1 has a resistance of 100 ohms, and the branch R_2 a resistance of 200 ohms, then, where R equals the value of the joint-resistance in ohms,

$$R=\frac{R_1 \times R_2}{R_1+R_2}$$
$$=\frac{100 \times 200}{100+200}$$
$$=\frac{20{,}000}{300}=66\ 2/3 \text{ ohms.}$$

As illustrated in Fig. 63, the same result may be ascertained graphically.

If two perpendiculars are erected at the extremities of a base line as shown, each perpendicular representing in height the value of the resistance of one

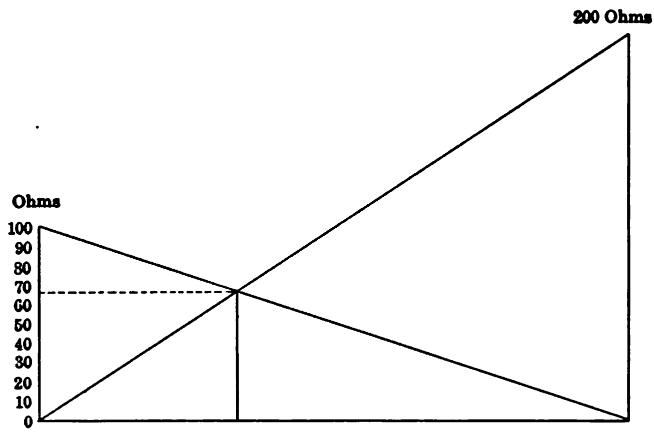


FIG. 63.

of the conductors of a divided circuit and two diagonals drawn as illustrated, a perpendicular extending from the base line to the point of intersection of the two diagonals will indicate the value of the joint-resistance of the two branches. A line drawn parallel to the base line and extending between the two outside perpendiculars through the point of intersection will indicate on either of the latter the joint-resistance in ohms.

When it is required to compute the joint-resistance of three or more conductors as in Fig. 64 or 64*a*, the same formula applies as in the case of a divided circuit having two branches. First the joint-resistance of any two of the branches is ascertained, and the result thus obtained combined in the same way with another of the conductors, and so on until all branches have been included in the calculation. To illustrate, suppose that in Fig. 64, R_1 has a resistance of 40 ohms, R_2, 50 ohms, and R_3, 60 ohms, then, combining R_1 and R_2 first, we have

$$\frac{40\times50}{40+50}=22\ 2/9 \text{ ohms}.$$

Combining the joint-resistance of R_1 and R_2 with that of the third branch, we have

$$R=\frac{22\ 2/9\times60}{22\ 2/9+60}=16+ \text{ ohms}.$$

If there were a fourth branch, the process would be continued in the same manner, that is, the joint resistance of the first three branches, 16+ ohms,

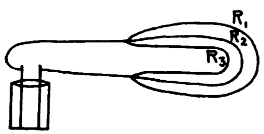


FIG. 64.

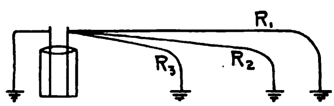


FIG. 64*a*.

would be combined with the resistance of the fourth branch as above explained.

The graphic method illustrated in Fig. 63 also may be used to determine the joint-resistance of three or more branches of a divided circuit. The derived perpendicular indicating the joint-resistance of the first two branches considered, would then have a diagonal drawn from its upper extremity intersecting a fourth diagonal representing the resistance value of the third wire, and so on.

Where it is desired to determine the joint-resistance of a large number of conductors connected in parallel it will facilitate the computation to employ the rule:

The joint-resistance of any number of conductors in parallel is the reciprocal of the sum of the reciprocals of the separate resistances.

Figure 64 represents a derived circuit having three branches. Let R_1, R_2, and R_3 represent the respective resistances of the three branches, then $\frac{1}{R_1}$, $\frac{1}{R_2}$, and $\frac{1}{R_3}$ are the separate reciprocals of the resistances of each branch. Therefore the joint-conductivity would equal

$$\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{R_2R_3+R_1R_3+R_1R_2}{R_1R_2R_3}$$

And, as the joint-resistance is the reciprocal of the joint-conductivity,

$$R = 1 \div \frac{R_2R_3+R_1R_3+R_1R_2}{R_1R_2R_3} = \frac{R_1R_2R_3}{R_2R_3+R_1R_3+R_1R_2}$$

Therefore

$$R = \frac{40 \times 50 \times 60}{(50 \times 60)+(40 \times 60)+(40 \times 50)} = 16+ \text{ ohms},$$

or the same result as was obtained by the first method.

Figure 64*a* shows several conductors leading from a source of e.m.f. and placed in contact with the earth as also is the opposite terminal of the battery. Electrical circuits arranged in this way are termed ground-return circuits, while the arrangement of conductors shown in Fig. 64 provides what is termed a metallic circuit.

In telegraphic practice, the earth is generally availed of as a return conductor. There are two or three different theories held pertaining to the part which the earth plays in completing electrical circuits, but so far as present purposes are concerned none of these theories are of practical importance. Suffice it that for ordinary requirements we are able to obtain a complete electrical circuit by using the earth as a part of circuits otherwise made up of metallic conductors.

Shunt Circuits.—In any combination of branch circuits, each branch acts as a by-pass for a portion of the current, and any branch carrying a portion of the current in a circuit is, in effect, a shunt to the other branches of the circuit thus divided. There are instances where the application of a shunt circuit requires that a definite value be given the shunt in order to regulate the amount of current flowing in a branch circuit connected in parallel therewith. For example, suppose it is required to provide a shunt "*S*," (Fig. 65,) having a resistance which will permit one-third of the total current in the circuit to flow through the 500-ohm coil shown on the right, what must be the resistance of the shunt?

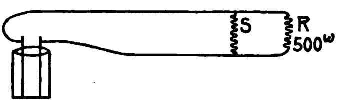


FIG. 65.

Let R represent the resistance of the circuit to be shunted,

n represent the multiplying power of the shunt,

S represent the resistance of the shunt,

Then

$$S = \frac{R}{n-1}$$

The value of n is arrived at when it is known what proportion of the current is to be shunted. In the case before us, it is required that one-third of the total current shall pass through branch R, therefore the multiplying power is 3, and

$$\frac{500}{3-1} = 250,$$

$$S = 250 \text{ ohms.}$$

To find the multiplying power of a shunt of known resistance, the following formula applies:

$$n = \frac{R+S}{S}$$

Suppose, for instance, that the multiplying power in the former example is unknown, and it is desired to learn the current proportions in each branch of the circuit.
Then

$$R = 500$$
$$S = 250$$

and

$$\frac{500+250}{250} = 3.$$

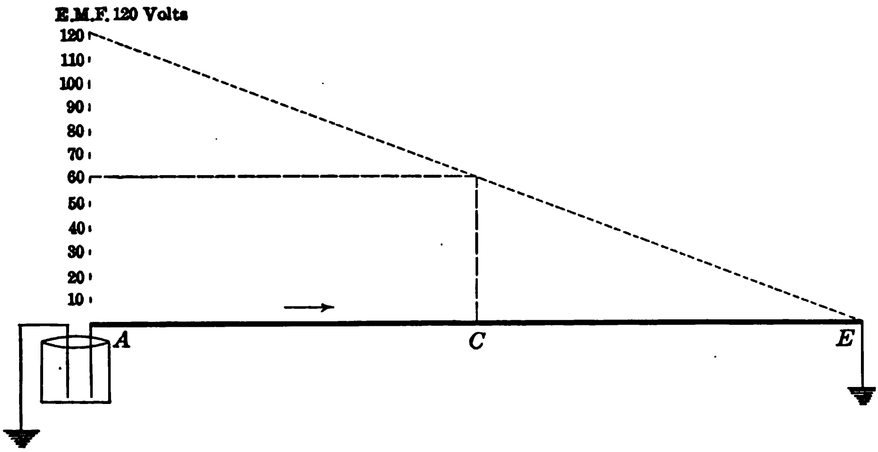


Fig. 66.—Fall of potential.

Fall of Potential in an Electric Circuit.—Some little confusion at times results from the use interchangeably, of the terms electromotive force and potential difference. In practice, it is usual to regard a primary battery, storage battery, dynamo-electric machine, or other generator of electricity as having a definite e.m.f., while an external circuit connected to the terminals of a given e.m.f. will have a difference of potential which decreases in value as resistance is overcome, in a direction from positive to negative terminal of the source of e.m.f. If a circuit external to the source of e.m.f. consists of a single conductor of uniform composition and uniform dimension throughout, and consequently of uniform resistance; it is found that the potential falls uniformly in a direction as stated above.

When a current flows in a conductor such as that illustrated by the heavy line *A–E*, Fig. 66, the difference of potential between the conductor and the earth at *E* decreases in the direction in which the current is flowing. If a

dotted perpendicular is erected at the battery end of the line representing the conductor; the height of the perpendicular representing the value of the e.m.f. in volts, and a horizontal line is drawn from the top of the former as shown, we have a means of determining the difference of potential between any specified point along the conductor and the earth.

For example, if it is desired to ascertain the difference of potential between a point (*C*) halfway along the conductor, and the earth, the erection of a perpendicular at that point between the base line and the dotted horizontal will indicate the difference of potential in volts as measured by an identical height of the perpendicular at the end of the base line; in this case, 60 volts. Obviously the difference of potential between any point along the conductor and the earth may be determined in the same manner.

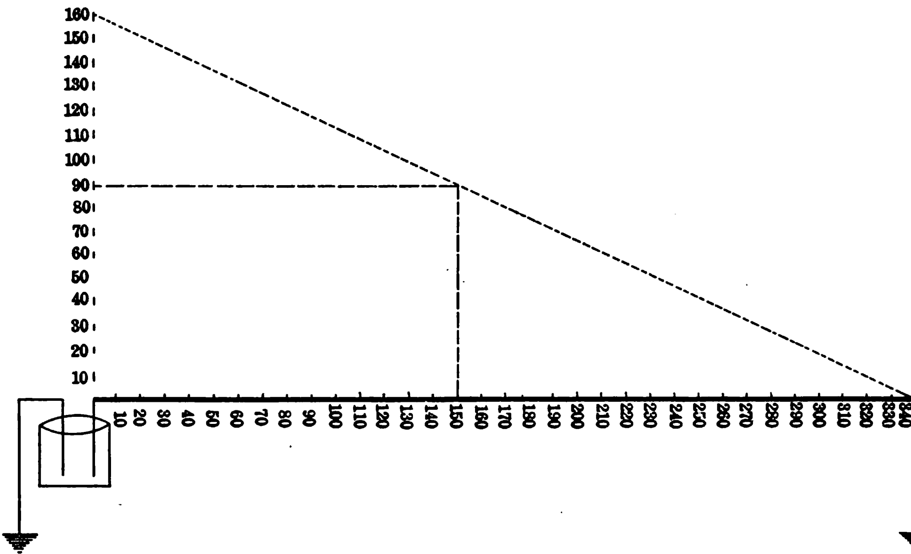


FIG. 67.—Fall of potential.

Consider a circuit such as that depicted in Fig. 67, where an e.m.f. of 160 volts is applied to a grounded circuit of 340 ohms resistance, and it is desired to ascertain what the difference of potential is at a point 150 ohms "distant" from the source of e.m.f. If the distance in ohms from 0 to 340 is properly graduated along the base line representing the conductor, and the e.m.f. in volts properly indicated along the perpendicular representing e.m.f., then a perpendicular erected at that point on the base line indicating 150 ohms will be found to have a height identical with the height of the perpendicular representing the e.m.f. at a point which indicates 90 volts, approximately; or, to be exact, 89.41 volts. Obviously the difference of potential at any point along the conductor, distant in ohms from the source of e.m.f., may be determined in the same manner.

The above graphical method of determining the difference of potential in a circuit while of considerable value in clearly setting forth the principles involved in the fall of potential, is seldom used in practice. A formula based on Ohm's law, and by which the same end may be attained, is given herewith:

Where E represents the applied e.m.f., in volts,
R represents the resistance in ohms, of the entire circuit,
R_1 represents the point distant in ohms from the source of e.m.f., where the value of the difference of potential is desired,

then

$$X=\frac{E(R-R_1)}{R}$$

Employing this formula to determine the difference of potential at a point 150 ohms distant from the source of e.m.f. in a circuit having a total resistance of 340 ohms (Fig. 67) and an applied e.m.f. of 160 volts, we have,

$$E=160$$
$$R=340$$
$$R_1=150$$

and

$$\frac{160\times(340-150)}{340}$$
$$=\frac{160\times190}{340}$$

$X=\frac{30,400}{340}=89.41.$ ans., 89.41 volts, or the same as was determined by the graphic method.

ELECTROSTATIC CAPACITY OF CONDUCTING WIRES

When, as "charge," electricity is present upon the surface of bodies, it is referred to as static electricity. In the operation of telegraph lines, static electricity, is encountered; generally as a disturbing agency, due to the fact that charge is accumulated on the surface of the conductor from both internal and external sources.

A knowledge of the principles of electrostatics is essential in the study of telegraphy, and while it is true that the subject is pretty well covered in text-books dealing with electricity and magnetism, the bearing which the subject has upon practical telegraphy has not always been clear to the student.

If one end of a telegraph line is connected with one terminal of a source of e.m.f., while the other terminal of the battery and the other end of the line are grounded (Fig. 68) it may be shown that when the key K is closed, current traverses the entire circuit almost instantaneously, affecting the distant end

of the conductor at nearly the same instant that the key is closed. The first indication of electrification at the distant end, however, is quite feeble, but the current strength increases gradually until maximum value obtains. If a current-indicating meter be inserted at the distant end of the line, there will be no deflection of its pointer until the current has attained a strength sufficient to energize the coils of the instrument thereby causing the indicating needle to move from its position of rest. The more sensitive the instrument employed for the purpose, the earlier will be the indication of current passing through it.

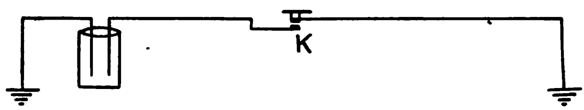


FIG. 68.

After the first movement of the needle has been observed, the amount of deflection will increase gradually until when maximum current obtains at the distant end, the pointer will have moved to a definite position, distant from its position of rest. On short lines the interval elapsing between the time the key is closed and the time constant-current is indicated is, of course, very brief. Should several current-indicating instruments be inserted at different points along the line as shown in Fig. 69, when the key is closed placing the source of e.m.f. in contact with the line, the instrument nearest the battery end of the

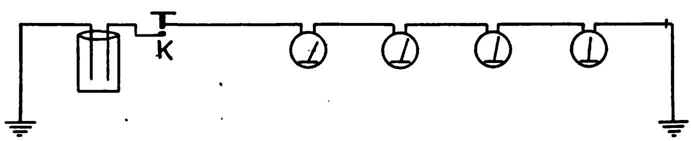


FIG. 69.

line will be the first to indicate the presence of current, the others following in order, each a fraction of a second later than the one behind it until the indicator located at the distant end of the line is affected.

From the foregoing it is apparent that current does not arrive at the distant end of a line "all at once" as does a bullet at a target. The initial portion of current flowing into a conducting wire is retained, or accumulated on the surface of the conductor, the quantity accumulated depending upon the length and surface of the wire, upon its distance from the surface of the earth, and upon the nature of the dielectric intervening between the conductor and the earth.

It is convenient to assume that the conducting wire absorbs the first portion of each charge sent into it, and that its capacity of absorbing electric charge has to be satisfied before constant current conditions obtain in the circuit of

which the conducting wire forms a part. The effect is as if the conductor requires to be "saturated" before delivering current at the distant end of the line, in a somewhat similar manner to that of a sponge, which has to be saturated to capacity before water drips from it.

It is found that when a circuit, such as that shown in Fig. 69, is closed by means of a key or otherwise, the indicating needles of the instruments located on the half of the line nearest the source of e.m.f. "over-shoot" the point at which they finally come to rest, while the indicating needles of the instruments located on the other half of the line have a continuously increasing angle of deflection until the conductor has become fully charged and normal current prevails, at which instant the needle has reached its maximum deflection and remains there. The conditions which obtain during the time the current is equalizing throughout the entire circuit is referred to as the variable state. The duration of the variable state varies in different circuits and depends upon the physical and electrical characteristics obtaining in any given instance.[1]

The permanent state has been established in a circuit when the current strength has been equalized in the conducting wire, or when the current value has become constant. The permanent state is first established in the middle of the line, at an instant practically four times sooner than constant-current conditions prevail at either end of the line. The statement that the "quantity of charge accumulated on the surface of a conducting wire, depends upon the dielectric intervening between the conductor and the earth," in so far as aerial lines are concerned, involves an understanding of the conditions prevailing at all points along the length of the conductor. When properly suspended and insulated, the conductor is enveloped in an insulating stratum of air, but this stratum varies in thickness as the conductor is carried past objects which are in contact with the earth.

As the surface of a conducting wire increases with its radius, the inductive capacity of the wire increases proportionately. The greater the inductive or electrostatic capacity of a conducting wire, the longer time it takes to charge it —the longer the duration of its variable state.

The electrostatic capacity of a conducting wire in effect diminishes the velocity of electrical action along the conductor, that is, each time the circuit is closed through a source of e.m.f. electrostatic capacity has the effect of retarding or delaying the initial appearance of current at the distant end of the wire.

In the transmission of telegraph signals over a wire, the circuit is closed and opened, say, four or five times per second, and in the case of long lines, the effect of electrostatic capacity is to considerably curtail the number of impulses or signals which may be sent over the wire in a given time. Where slow signal-

[1] A further treatment of the subject of capacity is given in Chapter X in connection with electric condensers, and in Chapter XI dealing with "Speed of Signaling," also see "The Capacity Balance," Chapter XV.

ing is concerned the effects of capacity are not of much consequence, but where high speeds are concerned the electrostatic capacity of a circuit may be the criterion of speed attainable.

Electrostatic Induction.—Where a charge of electricity of either sign (positive or negative) exists on a conductor, it will induce in neighboring conductors a bound static-charge of opposite sign on that side of the adjacent wires nearest to it and a charge of identical sign on the sides farthest away from it. See Fig. 69*a*.

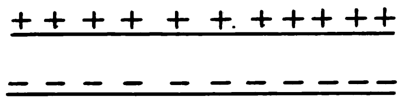


FIG. 69*a*.—Electrostatic induction.

The upper conductor is represented as having a positive charge and the interaction which takes place between the upper and the lower wires results in a bound negative charge being induced on the upper surface of the lower wire, while on the under side of the latter a free positive charge will appear. If the current in the upper wire should be changed from positive to negative, the reverse process would take place in the lower wire; thus, if the direction of current in the upper conductor is alternated from positive to negative and back again either slowly or rapidly a continuous interaction takes place between the upper and lower conductors.

Electromagnetic Induction.—Any conducting wire charged with current has surrounding it at all points along its length, lines of force in the form of closed rings or loops, and the space surrounding a charged conducting wire is

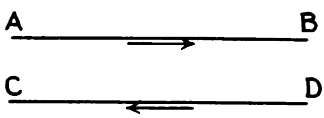


FIG. 70.

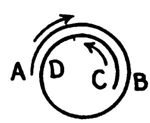


FIG. 71.

an active magnetic field. As will be described later in connection with the theory of electromagnetism, current in a circuit while increasing or decreasing in strength exercises an inductive effect upon neighboring circuits. It is true also that due to the expansion and contraction of the magnetic rings surrounding the conductor, as the circuit is closed and opened, there is an inductive action of the current in the conductor upon itself. Naturally this effect of self-induction is great if the circuit (as in the case of magnet coils) is made up of a coil of many convolutions, and much greater still when the turns of wire surround an iron core. If a current is caused to flow in the wire *A–B*, Fig. 70, in the direction indicated by the arrow, commencement of current or increase in its strength induces a current in the neighboring con-

ductor C–D in the direction indicated, or the reverse of the direction of current in the inducing circuit. In a circuit such as that shown in Fig. 71 where the conducting wire is coiled back upon itself, an increasing current flowing in the direction A–B in the outer convolution, induces a current to flow, or to attempt to flow in the opposite direction C–D. The induced current being greatly inferior to the original current in strength, results only in opposing the latter and delaying its rise to maximum strength. When the circuit is opened and the current strength in that portion of the circuit A–B is decreasing, it tends to induce a current between C and D in the same direction as that of the original current, and this results in prolonging the duration of the latter by virtue of the induced opposition to its decrease. In either case the effect of self-induction is to oppose change, and in a sense might be regarded as electromagnetic inertia. The fact that individual impulses are thus in turn retarded and prolonged diminishes the rate at which signals may be sent over long lines, as fewer distinct impulses can be transmitted in a given time.

In comparison with the effects of electrostatic induction, the effects of electromagnetic induction in lines of ordinary lengths is very slight. In very long lines the reverse is sometimes true. Where magnet coils are concerned, such as are essential in terminal apparatus, self-induction plays a prominent part in limiting the speed of operation over a given line, and in limiting the length of line over which satisfactory operation may be maintained.

The length of time required for an impulse to reach the distant end of a line and rise to a strength sufficient to operate receiving apparatus, particularly electromagnetic devices, depends upon the distributed electrostatic capacity and the ohmic resistance of the circuit. In fact, it has been deemed good practice to consider that the limits of satisfactory operation are proportional to the product of these two factors, which would mean that the product should be kept at as low a figure as practicable.

The electrostatic capacity of aerial conductors suspended at any height above the surface of the earth is intricately involved with the number of and relative proximity of other wires on the same pole line. A single No. 12 B. & S. gage copper wire suspended 30 ft. above the earth, with both ends grounded, was in one instance found to have a capacity of 0.009379 microfarads per mile and an inductance of 0.003149 henries per mile. Two similar wires placed 1 ft. apart and suspended 30 ft. above the earth were found to have a capacity between either wire and the earth of 0.012 microfarad per mile. For a line 500 miles long this would mean a total capacity of 6 microfarads.

It is important to note the difference in the interactions taking place between neighboring conductors, attributable to electromagnetic induction and to electrostatic induction.

Figure 72 gives a cross-section or end-view of two conducting wires carrying current. The closed loops shown perpendicular to and surrounding each

conducting wire represent the magnetic rings which exist during the periods that current is flowing in either direction through a conductor. If we suppose a condition such as that shown in Fig. 73 where current is temporarily suspended in one wire while current in the other wire is increasing or decreasing in strength, a current will be induced in the wire *B* due to its cutting the expanding and contracting magnetic rings, as they are called into being or destroyed, by the closing or opening of the circuit of which wire *A* forms a part.

As we proceed with the study of the various factors which have a bearing on the current strength in electrical circuits, it becomes apparent that Ohm's law, strictly speaking, is not applicable except where the factors are constant.

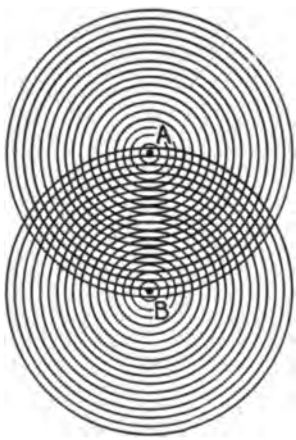


FIG. 72.

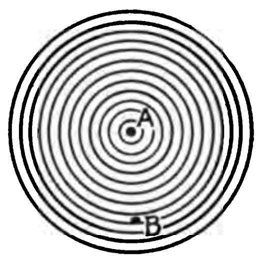


FIG. 73.

FIGS. 72 and 73.—Electromagnetic induction.

At the outset it is apparent that when a current of electricity is turned into a circuit for a brief instant and then interrupted, or when a circuit is first closed through a source of e.m.f., the current strength in the circuit for a short period is not truly represented by the formula

$$I=\frac{E}{R}$$

From what has been stated in regard to the effects of capacity and inductance in electric circuits, it is evident that the factor of "time" plays an important part in determining the current strength obtaining in a given circuit at a given instant.

Pulsatory currents of either polarity or currents which alternate in direction do not have a value in accordance with Ohm's law.

Helmholtz the great German physicist interpreted Ohm's law in a form which takes into consideration, the element of "time" and from this evolved

a formula which gives the current value in a circuit at any given instant, thus,

$$I=\frac{E}{R}\left(I-e^{-\frac{Rt}{L}}\right)$$

Where I, is the current in amperes,
E, is the applied e.m.f.,
R, is the resistance in ohms,
t, is the time in seconds,
L, is the inductance in henries,
e, is the base of the system of natural logarithms, or 2.7183.

In telegraph circuits operated at usual speed, it is obvious that the low value of the negative exponent in the above formula would give a determination practically agreeing with that obtained by means of Ohm's law, but if the value of t is reduced or the value of L is increased, a point is soon reached where the simpler law would not give a true indication of the condition.

The electrical properties as well as the physical properties of a circuit may be determined without regard to the e.m.f. to be applied to it. A telegraph circuit, including as it does the magnet winding of receiving instruments, offers a greater resistance to the passage of currents which alternate in polarity than is represented by the resistance of the circuit in ohms, the additional resistance being the direct result of inductance. The resistance in ohms combined with the inductance in henries produces impedance (symbol Z).

If L = the inductance in henries,[1]
N = cycles per second,
R = the resistance in ohms,
then

$$Z=\sqrt{R^2+4\pi^2N^2L^2}$$

Current in amperes

$$I=\frac{\text{e.m.f.}}{\text{impedance}}$$

Assume a circuit having values as follows:

R = 1,200 ohms,
N = 20 cycles per second,
L = 6 henries.

By means of the above formula the impedance (Z) may be shown to be 1,417, and the maximum current to be 141 milliamperes, where an e.m.f. of 200 volts is applied to the circuit; while Ohm's law

$$I=\frac{E}{R}$$

[1] A definition of the value of the henry is given in Chapter I, and a method of measuring inductance is described on page 103.

would give the current value as 167 milliamperes. Thus by considering frequency and inductance as factors, in the same sense that resistance is considered, it is possible to arrive at the true value of the current flowing in the circuit.

ELECTROMAGNETISM AND ELECTROMAGNETS

The phenomenon of magnetism may be exhibited by bringing a piece of iron into the neighborhood of a natural magnet (lodestone), permanent magnet or any form of electromagnet, where it may be attracted. If free to move, the iron will come into contact with and cling to the magnet. A powerful magnet will have an appreciable effect upon a delicately poised needle (see Fig. 74) even if the two are situated a considerable distance apart, and undoubtedly the influence of the magnet extends far beyond the boundary established by the methods ordinarily employed to determine its range.

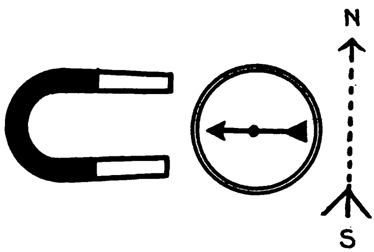


FIG. 74.—Compass needle deflected by the influence of a horseshoe magnet.

It is customary to consider iron as being peculiarly subject to magnetic influence, and as stated in the chapter on Electricity and Magnetism, steel, nickel, cobalt, chromium, manganese and other substances are similarly influenced to an extent varying in the case of each substance.

Also it is known that all kinds of matter possess this magnetic quality in some degree. It has been shown experimentally that temperature plays an important part in determining the magnetic susceptibility of a substance. Iron, for instance, when heated to 750° is irresponsive to magnetic influence, the reason, roughly stated, being that the atomic structure of the substance is so disarranged by high temperature that the atoms are unable to "line-up" magnetically in response to the influence of the inducing magnet.

Although for present purposes (investigating the properties of electric circuits), we may acquire the desired information relating to the magnetic properties of conductors carrying currents of electricity, by studying the magnetic action of solenoids, the further study of electromagnets requires that the connecting link between the two—the core—be treated of at the same time, or in connection therewith.

A helix of wire carrying a current of electricity possesses magnetic properties. When the helix consists of a coil of insulated wire and is wound around a bar of soft iron, the iron becomes magnetized when the electric circuit is energized, and the combination of helix and core is called an electromagnet. Substances in which a magnetizing force produces a high degree of magnetization, are regarded as possessing high permeability.

The intensity of magnetization, while in part dependent upon the strength of magnetic field produced by the helix, is also dependent upon the properties of the metal forming the core, that is, upon its permeability.

If a conducting wire connected through a source of e.m.f. is bent into a loop as in Fig. 75 the lines of force will thread through the loop from one end to the other in a direction depending upon the direction in which the current is flowing through the conducting wire. Should an iron core *M* be brought close to the loop of wire thus formed, the core would tend to enter the loop lengthwise, that is, place itself with its longest axis projecting into the loop of wire, and always in a direction the same as that taken by the lines of force. If the conducting wire is coiled into a helix or solenoid having a number of loops, as in Fig. 76, the lines of force around each turn or loop will reinforce those around neighboring loops, and the cumulative result will be the formation of numerous long lines of force as shown, which extend through the entire coil.

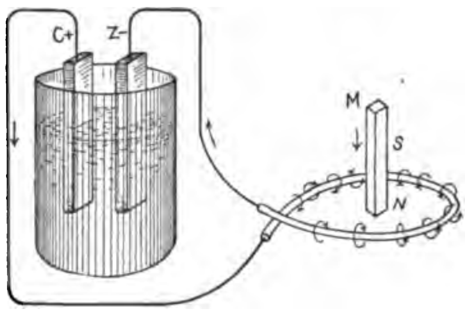


FIG. 75.—Direction of current in a completed circuit and resulting lines of force.

The above statements mean that the solenoid possesses properties identical with those possessed by bar magnets (permanent magnets). Inasmuch as the lines of force enter one extremity and leave at the other, the solenoid exhibits the phenomenon of polarity, having a north and a south pole. A coil such as that shown in Fig. 76 if traversed by an electric current, and suspended in a horizontal position, will, if free to turn, come to rest pointing in a north and south direction.

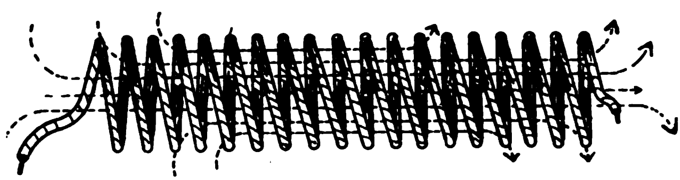


FIG. 76.—The solenoid.

The polarity of a solenoid is dependent upon the direction in which a current of electricity flows through it, and upon the direction in which the conducting wire is wound in forming the coil. The presence of an iron core very greatly increases the number of lines of force passing through the coil from end to end, the amount of increase being dependent upon the permeability of the substance forming the core. Obviously, when no core is inserted

in the coil there is a considerable amount of leakage of the lines of force out through the sides of the coil as indicated in Fig. 76, the total number extending all the way through being small compared with the number of lines carried to the polar extremities due to the concentrating properties of the iron core. In fact, the presence of a core not only reduces the leakage of lines of force but adds materially to those already existing.

As was stated on page 9, permeability (μ) equals $\frac{\mathcal{B}}{\mathcal{H}}$

where $\mathcal{B}$ represents the magnetic induction in lines of force per unit area of cross-section,

$\mathcal{H}$ represents magnetizing force.

Permeability.—Permeability might be referred to as that characteristic susceptible of expression through a numerical coefficient representing the ratio between the number of lines of force formed in a space containing air only, as in Fig. 76, and the number of lines formed in a space filled with a

FIG. 77.—The electromagnet.

given quality of iron as in Fig. 77. This ratio varies somewhat with different grades of iron and steel.

Magnetic resistance, or reluctance ($\mathcal{R}$), is less, the higher the coefficient of permeability, and, naturally the higher the permeability of a substance, the better it is suited for the purposes of electromagnet cores.

On page 25 the relative merits of various grades of iron and steel for field magnet core purposes were given in the order of their permeability; to these might be added silicon-steel, as the latter has been found to possess a high permeability and is being used to some extent in the manufacture of magnet cores.

The number of magnetic lines of force that can be forced through a core of given cross-section, while in great measure dependent upon the permeability of the substance of which the core is made, also has to do with the degree of magnetic saturation attainable with a given core material with given excitation, or, in other words, increasing the excitation beyond a certain point does not always increase the number of lines of force. In each case a point is reached beyond which there will be no increase of lines.

A specimen of iron when subjected to a magnetizing force ($\mathcal{B}$) capable of producing, in air, 52 magnetic lines to the square centimeter, was found to contain about 17,000 lines per square centimeter. By means of the formula $\mu = \frac{\mathcal{B}}{\mathcal{H}}$, the permeability in this instance would be 326 times that of air.

Good grades of wrought iron will carry approximately 20,000 lines per square centimeter, and cast iron about 12,000 lines. Figures considerably higher than these have been obtained where extraordinary magnetizing forces have been employed, but correctly plotted magnetization curves show that there are pronounced evidences of saturation when the values reach those above stated. It will be remembered that the value of $\mathcal{B}$ is given in gausses, the definition of the unit being stated on page 8.

The following table of values of $\mathcal{H}$ and $\mathcal{B}$ from samples of first grade American wrought iron, were determined by Dr. Sheldon, and the magnetic permeability in each case may be ascertained by means of the above formula:

$\mathcal{H}$	$\mathcal{B}$ (Gausses)
10	13,000
20	14,700
30	15,300
40	15,700
50	16,000
60	16,300
70	16,500
80	16,700
90	16,900
100	17,200
150	18,000
200	18,700
250	19,200
300	19,700

The magnetomotive force or magnetization of an electromagnet is proportional to the number of turns of wire wound around the core, and the current in amperes flowing through the coil.

A unit pole will have 4×3.1416 lines of force proceeding from it, or to reduce to c.g.s., units

$\frac{4\pi}{10} = 1.25764$, which is generally taken at the value of 1.257.

Where N = the number of turns in the coil,

I = the current in amperes.

Magnetomotive force $\mathcal{F}$ (Gilberts)

$$= 1.257 \times N \times I.$$

A field of $\mathcal{H}$ units refers to one where there are $\mathcal{H}$ dynes on unit pole, and it is customary to follow the rule of drawing a number of lines of force to the square centimeter of cross-section of the core equal to the number of dynes of force on the unit pole.

Unit of Work.—The unit of work, the erg, refers to the amount of work done when a force of 1 dyne is overcome through a distance of 1 cm., or, in other words, the amount of work done in moving a body through a distance of 1 cm. against a force of 1 dyne.

A unit magnetic pole has as many lines of force proceeding from it as there are square centimeters on the surface of a sphere of 1 cm. radius. A sphere having a radius of 2 cm., obviously has a diameter of 4 cm., and an area of $D^2 \times 3.1416$. A sphere having a radius of 1 cm. has a surface area of $2^2 \times 3.1416 = 12.5664$ sq. cm., therefore, unit magnet pole of unit strength has 12.5664 magnetic lines of force.

As 1 sq. in. is equal to 6.452 sq. em., it follows that when unit density of magnetism concerns a density of 1 magnetic line of force per square centimeter, we have an equivalent value of 6.452 lines per square inch as unit density of magnetism. In a magnetic circuit, magnetomotive force corresponds to electromotive force in an electric circuit. Reluctance, or magnetic resistance in a magnetic circuit corresponds to ohmic resistance in an electric circuit, or

$$\text{Flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}.$$

Magnetic flux (The Maxwell, Symbol Φ) is, therefore, dependent upon magnetic reluctance (The oersted, symbol $\mathcal{R}$) the latter being a property which tends to oppose the passage of magnetic flux. As previously stated, however, the magnetomotive force may be measured in terms of ampere-turns (the ampere-turn is equal to 1.26 Gilberts).

Hysteresis.—When the iron or steel core of an electromagnet has been magnetized by a current of electricity flowing through the magnet winding, and the exciting current is discontinued, the core will be found to retain more or less magnetism. The magnetism remaining is termed residual, and its value is spoken of as remanence.

A completely closed magnetic circuit, that is, one where the "keeper" or armature is in mechanical contact with the pole-faces of the magnet, will show much greater remanence than one having an air gap between the armature and the polar extremities of the magnet. When an electromagnet is permitted to draw its armature into actual contact with its pole-faces, the armature will not fall back instantly when the exciting current is discontinued, due to the fact that it is held fast by the residual magnetism of the cores. It is for the purpose of avoiding this that electromagnets are generally so arranged with regard to the moving element—the armature—that mechanical contact between the armature and the pole-faces does not occur in practice.

It is common practice to set a small brass pin in the face of each magnet pole, the pin projecting about one-sixteenth of an inch, or a distance sufficient to prevent the armature from coming into actual contact with the pole-faces proper.

The brass pin is really a safety stop, as receiving instruments used in telegraphy, which consist mainly of an electromagnet and an armature are so designed that the armature "plays" between a front and a back "contact,"

both adjustable, and which limit the travel of the armature within any desired space.

Magnetic materials manifest a tendency to resist any change—either increase or decrease—in their magnetic condition, a characteristic which might be regarded as a sort of magnetic inertia, and which is known as hysteresis.

An effect of hysteresis is to cause a delay, or "lag" in the magnetization of the core, behind the energizing current traversing the winding of the magnet. When a circuit including an electromagnet is closed, the relation between the exciting current and the magnetic flux produced will be such that maximum magnetization will lag somewhat behind the maximum electrical excitation of the winding. The result being that there will be a time interval of a fraction of a second between the time the electrical circuit is closed, and the time maximum magnetic flux is produced.

A part only of this delay is chargeable to hysteresis, for, as was pointed out in connection with the effects of self-induction, the latter phenomenon is directly responsible for the delay observed in the increase and decrease of electric current in the coil winding, which in turn delays the increase and decrease of magnetization of the core.

Time-constant.—When a constant e.m.f. is impressed on a circuit including a magnet coil possessing inductance, the current flowing in the circuit does not reach its full value instantly, as at first it is opposed by the counter electromotive force due to inductance. The counter e.m.f. gradually becomes less as the current value reaches full strength. In practice it is usual to regard the operating requirements as such that a value of 63.2 per cent. of the full strength of the current should obtain in an efficiently operative circuit. The period required to attain this value is called the time-constant of the circuit.

$$\text{Time-constant (in seconds)} = \frac{\text{inductance (in henries)}}{\text{resistance (in ohms)}},$$

or

$$= \frac{\text{henries} \times \text{final amperes}}{\text{applied volts}}.$$

As usually submitted the first formula is given as

$$\text{Time-constant} = \frac{L}{R}.$$

Suppose for example that it is desired to determine the time-constant of a relay having a resistance of 300 ohms, and an inductance of 2.65 henries. For L we have a value of .265 and for R a value of 300, and

$$\frac{2.65}{300} = 0.009,$$

or a time-constant of 0.009 second.

Assume a circuit including an electromagnet to have a resistance of 600 ohms and an inductance of 6 henries, then with an e.m.f. of 40 volts applied to the circuit the time-constant would be

$$\frac{6}{600}=0.01 \text{ (second)}.$$

By means of the formula

$I=\frac{E}{R}$, the final current strength in the circuit would be

$$\frac{40}{600}=0.066 \text{ ampere},$$

therefore in 0.01 second the current strength in the circuit will have reached a value of 0.041 ampere, or 0.632 of its full strength.

The same result could have been obtained by means of the second formula, or

$$\text{Time-constant } =\frac{L\frac{E}{R}}{E}$$

$$=\frac{6\times 40}{600}\div 40=0.01 \text{ second}.$$

The several electrical and mechanical actions which govern the forward and backward movement of the armature of a telegraph relay, thus are involved with the element of time, even if but a fraction of a second is consumed with each transit. The time-constant, therefore, of the circuit refers to the time in seconds, or fractions thereof, which it takes the current strength in the circuit to build up to a value approximately two-thirds that of its final strength. On the other hand, after the armature has been attracted toward the pole-faces of the magnet, and the circuit again opened or discontinued, it requires an appreciable time for the magnet to "let go" the armature or to release it. Careful experiments have shown that after the magnet circuit has been opened, the average time required for a magnet to release its armature varies from 0.003 seconds with maximum retractile spring tension to 0.033 with minimum retractile tension. Average operating adjustments obviously give "releasing" values about midway between these figures.

In determining the time-constant of a circuit which includes electromagnets by either of the above formulæ, it is required that the inductance be known. In cases where the impressed electromotive force varies according

to the Sine law of alternating currents and the inductance (L) is constant, the effective value of the inductive counter e.m.f. is

$$E = 2\pi fLI, \text{ where}$$

f represents "frequency" or cycles per second,

I the effective value of the current,

E would then be the inductive reactance, or the inductance of the circuit.

Another method, and one more applicable in approximating the inductance of magnets used for telegraphic purposes, is that known as the "standard condenser" method.

By means of a Wheatstone bridge and an adjustable condenser arranged as shown in Fig. 78, the inductance of a magnet, a pair of magnets, or an "instrument" may be determined quite accurately.

The four arms of the bridge, namely, a, b, x, and R, are shown in their respective positions. G is a galvanometer, r an adjustable resistance, and C an adjustable condenser.[1]

The "instrument" to be measured for inductance is inserted at X, then, after the bridge has been balanced; that is, after R has been adjusted to equal the resistance of X (a condition which is indicated when the galvanometer pointer remains in the center of the scale and unaffected when the keys K and K_1 are closed) if the key K_2 is now closed, it will be found that when the keys K and K_1 are closed and opened at short intervals, the galvanometer pointer will be "kicked" to one side or the other due to the counter e.m.f. of induction from the magnets located in the X arm of the bridge. The counter current thus produced is obviously of but momentary duration and results in the galvanometer pointer being "kicked" to the right or to the left (depending upon the direction of the flow of current through the galvanometer), the pointer immediately returning to "center." All that is required to determine the inductance of the coil X is to adjust r and C until there is no "kick" when the keys K and K_1 are closed. Then, if the arms a and b each have 100 ohms resistance inserted as shown in Fig. 78, the inductance may be determined by means of the formula

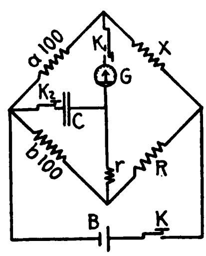


FIG. 78.—Condenser method of measuring inductance.

$$h = C[r(R+100)+R\times 100],$$

where h is the inductance in henries.[1]

[1] The resistance units which make up the values in arms a, b, and R are practically non-inductive, as the resistance wire wound on the "bobbins" making up the various units is "doubled back" on itself, so that the lines of force produced in one-half of each coil are "neutralized" by those produced in the other half, thus nullifying the inductive action of the coil as a whole.

PRACTICAL ELECTROMAGNET DATA

Self-induction is proportional to the square of the number of turns of wire in an electromagnet, everything else being equal.

Connecting the windings of a pair of magnets in "parallel" reduces the time-constant one quarter.

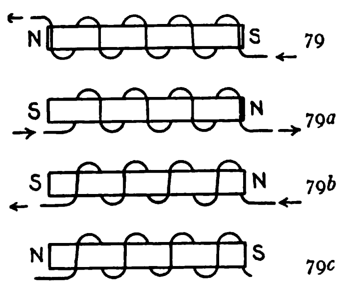
From the formula

$$\text{Time-constant} = \frac{L}{R}$$

it is obvious that the time-constant of a circuit, including electromagnets, may be reduced by reducing the self-induction or by increasing the resistance.

With the armature mounted so that a distance of 0.010 in. or more separates it from the pole-faces of the magnets, maximum pull is obtained when "flat" pole-faces are employed. When the distance separating armature and pole-faces is less than 0.010 in., pointed or concave poles are more effective.

The efficiency of a magnet is independent of the resistance of the winding. It is immaterial whether a thick or a thin conducting wire is used, provided the thickness of the wire is sufficient to carry the required current, and that the same number of watts are spent in heating it. Heat waste in a magnet coil is proportional to the square of the current in amperes; magnetizing power of the coil is simply proportional to it. With rapidly varying currents, Hughes found that with a given number of turns, the strongest pull is obtained when the turns are "heaped" near the poles. With constant currents the best results are obtained when the winding is distributed uniformly over the core.



FIGS. 79–79c.

There is less magnetic leakage between cores, and less wire is required per turn, when round cores are used.

With small current values, maximum effect is obtained when the poles are situated 1.17 in. apart.

With the armature in contact with the pole-faces of the magnets, the magnetic leakage amounts to 7 per cent. With the armature situated 0.004 in. away the leakage amounts to 53 per cent.

The number of turns of wire in a single magnet

$$= \frac{L(D-d)}{2G^2}$$

Where L = the length of the winding space in inches,
D = the diameter of the winding space in inches,
d = diameter of the core in inches,
G = the diameter of the wire, including insulation.

Coil data for the construction of a 150-ohm main-line relay of a certain type is as follows:

Core: length, 1 21/32 in., diameter 3/8 in.

Winding space: length 1 5/16 in., diameter 27/64 in.

Turns of wire: 3,990 turns of single silk-covered wire No. 31, on each spool.

As before stated, the direction of winding, and the direction of current through the conducting wire, determine which is the south and which the north "pole" of the magnet.

Figures 79, 79*a*, 79*b*, and 79*c* show the north and south poles, respectively, for each combination of current direction, and direction of winding.

CHAPTER VII

SINGLE MORSE CIRCUITS

The term "Single Morse line" is generally applied to those circuits which are so equipped and operated that transmission is carried on in one direction only at a time.

The equipment, in the way of apparatus, of circuits so operated is quite simple; in most cases, consisting of a "relay," a "sounder" and a "key" at each station or office connected in the circuit. With the exception of those single circuits where an unusually large number of offices are connected into an individual circuit, the satisfactory operation of single Morse circuits does not present any serious engineering problems. In general, the requirements are uniformity of relay resistance, sufficient current volume to operate the relays, proper insulation of lines, and proper adjustment of armatures and electromagnets of both main-line and local instruments.

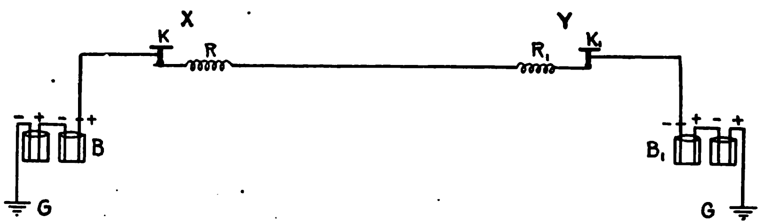


FIG. 80.—Single Morse circuit.

It may be stated that these same factors constitute the requirements of satisfactory operation of any system of telegraphy employing connecting wires, and while in a measure this is true, the fact remains that in the operation of other systems, such as "automatics," "printing systems," "multiplex systems," etc., the factors above mentioned assume greater importance, and in the operation of the latter there are involved many other factors, some related to, and some foreign to the essential elements above enumerated.

The simple Morse circuit illustrated in Fig. 80 operates upon the principle that an electromagnet may be alternately magnetized and demagnetized by closing and opening an electric circuit of which the electromagnet forms a part.

Figure 80 represents a telegraph circuit consisting of a line wire stretching between stations Y and X, main-line batteries B and B_1, electromagnetic

relays R and R_1, and keys K and K_1. To avoid the expense of a return conductor between the two stations in order to "complete" the circuit, the line wire after being connected through the instruments at either end is "grounded," that is, connected with the ground by means of an "earth" plate buried a few feet below the surface of the earth, or by a metal rod driven into the earth to a depth of 4 or 5 ft.

The completed circuit thus consists half of conducting wire and half of earth. In addition to the saving in length of conducting wire required for each circuit, this method has the further advantage that the electrical resistance of the circuit completed through the earth is considerably less than if completed by means of a return wire, as the resistance of the earth is practically negligible.

Electrical circuits made up in this way are called "ground-return circuits."

When the circuit depicted in Fig. 80 is closed by means of the key K, (provided the key K_1, also is closed) current traverses the circuit, energizing relays R and R_1, causing them to attract their respective armatures. The effect upon the relays at both stations is the same whether the key K or K_1 is used for the purpose of opening and closing the circuit. This means that manipulating the key at either station results in the simultaneous operation of all of the relays connected in the circuit.

In the original systems of telegraphy the electromagnetic instrument used in place of the modern "relay" consisted of a conveniently mounted pair of magnets, the accompanying armature of which was attached to one end of a lever having a pointed steel stylus at the opposite end which indented a mark, either long or short—depending upon the length of time the circuit was kept closed—upon a strip of paper tape continuously moved along under it by means of clock-work, or weight-driven gear. A momentary contact produced a short mark, or "dot," while a longer contact produced a longer mark or "dash," thus by alternately closing and opening the circuit by means of the sending key, in forming combinations of dots and dashes to represent the different letters of the alphabet (such, for instance, as "a dot and a dash" for the letter "a," "a dash and three dots" for the letter "b" etc.), messages could be transmitted over the line and "registered" on the receiving tape in "dot and dash" signals.

A later development of the receiving "register" provided for an inked reproduction of the received signals. That is, the received signals in the form of dots and dashes were marked on the tape by means of an inking-wheel, instead of being indented in the paper as in the original device.

It was not long, however, until tape methods of receiving signals were superseded by the method at present in use; that of receiving the signals by "sound." In the latter method the main-line relay in turn operates locally a "sounder" somewhat similar in construction to the relay itself but so designed mechanically that it gives forth a greater volume of sound, the

dots and dashes of the telegraphic alphabet being recorded audibly, and instantaneously interpreted by ear. Copying the received message by "sound" requires that the operator must be thoroughly familiar with the alphabet; in fact, to an extent that enables him to recognize the Morse characters instantaneously and without having recourse to a tape record of the received message.

Referring again to Fig. 80, it may be observed that the main-line battery at one station is connected to coincide with the battery at the other station. If the station *X* has the positive pole of his battery "to line" the battery at station *Y* is connected with the negative pole to line.. This arrangement provides for a continuation of the "series" connection of cells, part of the battery being located at one end of the line and part at the other end.

In many cases the battery for the entire line is located at one end of the circuit. In practice it is quite often economical and convenient to maintain all of the battery required to operate the circuit or circuit at one end only.

One disadvantage of this arrangement is that in case the line becomes grounded any distance away from the end at which the battery is located, the stations beyond the "ground" are unable to communicate with each other owing to the fact that the line beyond that point is without battery, while in those instances where battery is maintained at each end of the circuit, offices on each side of the temporary ground connection may keep up communication with each other locally during the enforced interruption to the through circuit.

On single circuits such as those under consideration, an indefinite number of intermediate offices may be introduced in the circuit between the two terminal offices, each intermediate office being equipped with its relay, key, and sounder. The manipulation of any key connected into the circuit operates all of the relays simultaneously. When any key is being used to transmit signals it is necessary, of course, that all other keys be kept closed, except for the purpose of "breaking" and calling for the repetition of doubtful words on the part of the operator receiving the message. This is what is known as the "closed-circuit" system.

THE LOCAL CIRCUIT

Main telegraph lines stretching between towns and cities have a comparatively high resistance, and, generally speaking, it is more convenient and economical to employ a main-line receiving instrument designed to operate on a small volume of current, say, from 40 to 75 milliamperes, rather than an instrument which requires large current volumes.

With a current of less than one-tenth of an ampere a sufficient magnetic force is not developed in the electromagnets of a receiving instrument to attract the armature with the power necessary to produce an adequate vol-

ume of sound when the armature strikes the "stop" screws in the act of reproducing the received signals.

In order to obtain a satisfactory volume of sound it is necessary to employ armatures having considerable size and weight, and the satisfactory operation of such comparatively large moving parts requires strong magnetic action on the part of the electromagnets actuating the armature.

Instead of employing large currents to overcome the resistance of the entire line conductor in order to obtain strong magnetic action in the receiving instrument, it is much more economical to use a sensitive receiving instrument operated on low-current values, and to provide that the armature of the more delicate line instrument shall automatically close and open a "local" circuit in response to the closing and opening of the main-line circuit.

It is an easy matter to arrange for current values in the local circuit

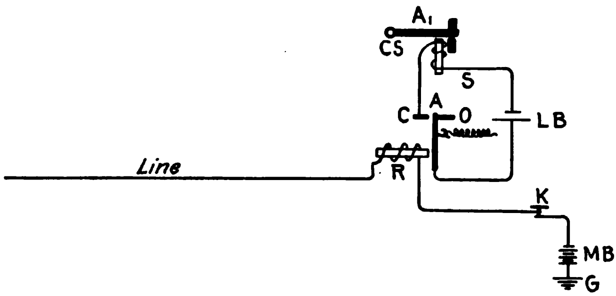


FIG. 81.—The sounder circuit.

to suit the requirements, as there is no resistance to be overcome except that of the magnet windings of the local instrument used as a "sounder" and the comparatively short lengths of conducting wire necessary to make the desired connections.

Figure 81 shows theoretically the connections of one end of a single Morse circuit, with relay *R*, key *K*, and main battery *MB*, connected in series in the main-line circuit, while the local circuit with local battery *LB*, and sounder *S*, are connected in series through the armature *A*, and closed contact *C*, of the relay. The operation of the local or "reading" circuit may be readily traced. When the main circuit or line is closed, the relay magnet attracts its armature and closes the local circuit, in which is located the magnet of sounder *S*. The relay armature is of such light construction that a weak current is sufficient to operate it, while the resistance of the local circuit is so low that practically the entire force of the local battery is available to operate the sounder.

It may be noted that although the local circuit depends for its operation upon the operation of the main circuit, the latter is separate and independent of the former and is in no way affected by its action.

OPEN-CIRCUIT SYSTEM

A main-line circuit may be arranged between two stations as shown in Fig. 82 (a system much used in Europe), in which a main-line battery situated at either end of the line is brought into action only when the line is in use for the actual transmission of signals. In the diagram, two terminal stations and an intermediate station are shown, each having a battery, relay, and key. The main-line connection is made to the "lever" of the key, thus the circuit divides at that point into two branches, but one of which can be closed at one time. One of the branches includes the battery and the ground connection only, while the other takes in the magnet windings of the relay and continues to the ground connection. Normally the key at each station rests in a position which closes the line circuit through the receiving relay to ground.

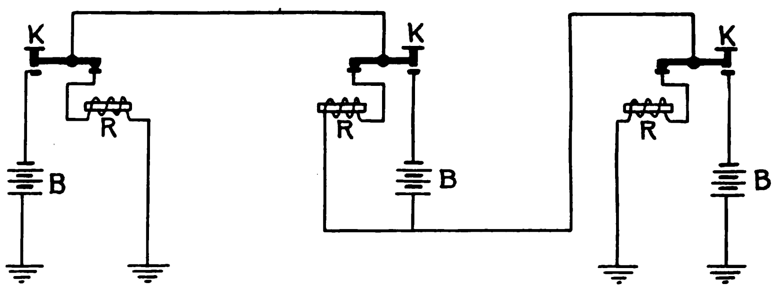


FIG. 82.—"Open circuit" Morse system.

The transmission of signals is accomplished by depressing the key, which establishes connection between the battery and the line, and as the receiving relay at the distant station is normally in the main-line circuit, the signals transmitted from the sending station are received in the same manner as in the closed-circuit system (for the sake of simplicity the local circuits at each station have been left out of the diagram, Fig. 82).

While, in this country there are not many telegraph circuits which are not in use the major portion of the day, the open-circuit system, permitting as it does of the use of dry cells, affords a simple and comparatively economical means of operating short wires, private lines, and lines between points remote from regulation sources of electric current, where the transportation, setting up and maintenance of chemical batteries might involve objectionable features. The connections as shown in Fig. 82 are such that the relay at the sending station does not record the outgoing signals, the object being to eliminate the resistance of the relay at the sending station during the transmission of a message so that a greater volume of current will be available to actuate the other relays in the circuit. Where this system is used, in

some instances a low-resistance galvanometer is provided and inserted on the "line" side of the key at each office for the purpose of giving the sending operator an indication of the outgoing signals. It is obvious, however, that where a sufficient number of cells of battery are used, the relay connected into the circuit at each office could be inserted as shown in Fig. 83 instead of as shown in Fig. 82, in which case the outgoing signals would be recorded on the home relay in the same way as in the closed-circuit system of operation.

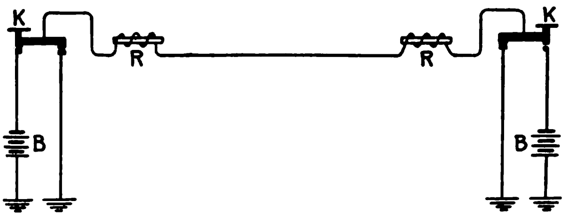


FIG. 83.

SEVERAL LINES WORKED OUT OF A SINGLE BATTERY

It is a singular fact that a source of e.m.f. having a sufficient output to operate one line will work several lines with equal facility, provided there is not too great a difference in the lengths or resistances of the individual conductors. In practice, variations in length of the several conductors connected to a single-battery or dynamo-electric machine may be compensated (in the case of a very short line, or one having low resistance in comparison with the other lines being fed by the battery) by inserting an additional resistance in the form of a coil of wire in series with the low-resistance line, so that its total resistance will be raised to a value which will prevent the short wire acting as a low resistance path to ground for the battery current.

A No. 8 B. W. G. iron wire weighing 380 lb. per mile has a resistance of 12.37 ohms per mile at a temperature of 68° F., and a No. 9 B. & S. gage copper wire weighing 208 lb. per mile has a resistance of 4.39 ohms per mile at the same temperature.

Assume that we have a ground return circuit connecting two terminal stations 100 miles apart, and that there are two intermediate offices connected in the circuit, and that each station is equipped with a receiving instrument having a resistance of 150 ohms. If the source of current to operate the line consists of a gravity battery, and a current of 50 milliamperes is required to satisfactorily operate the circuit, first ascertain the resistance of the line, including the resistance of the windings of the magnets of all of

the receiving instruments in circuit. Then, assuming that the line conductor consists of No. 8 iron wire, we have

100 miles of No. 8 iron wire at 12.37 ohms per mile	=	1,237 ohms,
4 receiving instruments each having 150 ohms resistance	=	600 ohms
Total,		1,837 ohms.

The number of cells of gravity battery required to furnish 50 milliamperes of current through a resistance of 1,837 ohms may be ascertained by means of the formula given on page 75. In this instance the values of the various factors are

$$R = 1{,}837 \text{ ohms},$$
$$E = 1.07 \text{ volts}$$
$$r = 2.5 \text{ ohms},$$
$$I = 0.050 \text{ ampere}$$

and as the number of cells $(N) = \dfrac{R}{\dfrac{E}{I} - r}$

then

$$\frac{1{,}837}{\dfrac{1.07}{0.050} - 2.5} = 97 \text{ cells}.$$

The reason that the law

$$I = \frac{E}{R}$$

does not correctly apply for this purpose is that each cell of battery has a resistance of 2 1/2 ohms, and the 97 cells place an additional 243 1/2 ohms resistance in the circuit. However, after the value of E for the entire battery has been determined by the above method, the simpler formula $I = \dfrac{E}{R}$ may be employed to check the result. The example here considered, where the resistance per mile of the conductor has been multiplied by the number of miles, assumes perfect insulation of the line.

The 97 cells of battery required to furnish 50 milliamperes current would not necessarily have to be located at one end of the line, but might be distributed, part at one end and part at the other, in which latter case opposite battery "poles" should be placed to line at each terminal station—positive at one end and negative at the other.

If the source of e.m.f. availed of to furnish current to operate the line above considered were a dynamo, then the formula $I = \dfrac{E}{R}$ would serve the purpose, as the internal resistance of the dynamo is so low as to be negligible.

Suppose two terminal stations situated 500 miles apart are connected by a No. 9 copper wire, and that there are two intermediate stations in the circuit, each station, including the two terminals, being equipped with receiving instruments having 150 ohms resistance (Fig. 84). If we assume the line to be perfectly insulated and it is desired to ascertain the voltage necessary to maintain 45 miliamperes current in the circuit by means of the formula $E=I\times R$, the required potential may be arrived at thus:

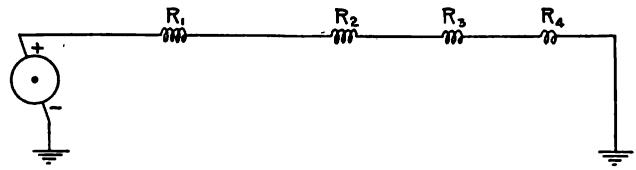


FIG. 84.

$I=0.045$ ampere
$R=(4.39\times 500)+(150\times 4)=2,795$ ohms,

and

$2,795\times 0.045 =125.775$, or 126 volts.

In this example we have not allowed for the insertion of any additional resistance in applying the e.m.f. to the circuit. This imposes the requirement that the source of e.m.f. must have very little or no internal resistance if 45 milliamperes current is to be maintained in the external circuit.

As previously stated, several lines may be worked out of one battery, and in practice it is found that when the internal resistance of the source of

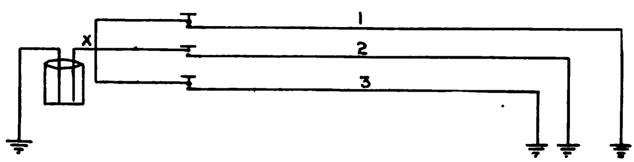


FIG. 85.—Several lines fed from a common battery.

e.m.f. is infinitely small in comparison with that of the several lines connected thereto, the strength of the current in each circuit will be practically the same as if it were the only line attached to the battery. In view of this when a number of lines are "fed" from a common battery it is immaterial whether but a single line is operated, or whether several lines are operated simultaneously.

By reviewing the calculations in connection with Figs. 64 and 64*a* on page 85, dealing with joint-resistance, the student will be better able to understand the explanation of this seeming inconsistency in the behavior of electric currents.

When a single line is being fed from a battery, and a second and a third line are connected to the same source as in Fig. 85, the total amount of current flowing from the battery divides along three paths and when all three circuits are closed, that is to say; taking current, the aggregate sectional area of the conductor is so increased that the total resistance which limits the volume of current flowing from the battery is greatly reduced, and as the strength of current taken from the battery increases in the same proportion, the loss which would result from the division of the current into three separate branches is compensated for by the increased current strength due to the reduction in resistance of the circuit as a whole.

The maximum current efficiency may be derived from a battery when the total internal resistance of the battery equals the resistance of the external circuit. Of course, actual conditions are such that it is not convenient, or for that matter necessary to maintain this balance of resistance between the external and internal portions of the circuit, but it is due to this that the gravity cell, with its comparatively high internal resistance per cell (2 1/2 ohms), has met the requirements so satisfactorily, and that this type of battery has been so extensively employed in the operation of telegraph lines. The longer the line, or rather the greater the resistance of the line, the better does this type of cell answer the purpose, but this is true only when each separate line has its own battery.

When the battery is required to feed several lines, the internal resistance becomes an important factor. By considering the conditions which prevail in a case such as that depicted in Fig. 85 it is evident that the internal resistance of the battery will remain constant while the resistance of the circuit beyond the point X will vary considerably, depending upon the number of branches which are closed at one time. As the battery resistance then becomes an important part of the total resistance of the circuit, the former should be kept as low as is practicable, for, no matter whether one or more lines are being operated at the same time, each line should have equal current strength.

When a battery composed of gravity cells is employed to feed several lines, the current volume in each separate circuit varies according to the number of circuits which are closed at the same time.

Suppose, for instance, that five separate lines each having a total resistance of 1,200 ohms are fed from a gravity battery having a total e.m.f. of 100 volts and a total internal resistance of 200 ohms, then with one circuit "closed" and the other four open, the current value in the closed conductor would be

$$I = \frac{E}{r+R}$$

$$= \frac{100}{200+1,200} = 71 \text{ m.a.}$$

With all five circuits closed, the current value obtaining in each circuit may be determined by means of the formula

$$I=\frac{E}{r+\frac{R}{N}}\div N$$

$$=\frac{100}{200+\frac{1,200}{5}}\div 5=45 \text{ m.a.}$$

Or, as the five circuits are operated simultaneously or intermittently the volume of current in each conductor will fluctuate between 45 milliamperes and 71 milliamperes, depending upon the number of circuits which are closed at one time. In this particular instance the discrepancy between maximum and minimum current values in any one circuit may not be great enough to be regarded as unsatisfactory, but it should be noted that the conditions are such that the minimum current value is still high enough to operate the usual type of receiving instrument under favorable conditions, also the resistance of each of the five lines is identical, and further; but five lines are being fed from the battery. Obviously, if the number of lines were increased, or if the individual resistances of the various lines should be unequal, the unsuitability of primary batteries for the purpose of supplying current to many lines would be more apparent. If, for instance, the number of lines in the above example should be increased to six, then (other conditions remaining the same) the minimum current would be 25 milliamperes, a value too low for single-circuit operation.

Where secondary-cells or dynamo machines are employed to furnish current to operate telegraph lines, the negligible internal resitsance of these sources of e.m.f. fulfills the condition previously referred to "where the internal resistance of the source of e.m.f. is infinitely small in comparison with that of the several lines connected thereto," and if the five lines considered in the above example were supplied with current from a dynamo having an e.m.f. of 100 volts, the current strength in the closed conductor (the other four remaining open) would equal

$$\frac{100}{1,200}=83 \text{ m.a.}$$

and with all five circuits closed,

$$\frac{\frac{100}{1200}}{5}\div 5=83 \text{ m.a.}$$

If instead of five circuits, ten are connected to the same source of e.m.f. the current value in one closed circuit would be

$$\text{I}=\frac{100}{1200}=83 \text{ m.a.}$$

and with all ten circuits closed simultaneously, the current volume in each circuit would be

$$I = \frac{100}{\frac{1200}{10}} \div 10 = 83 \text{ m.a.}$$

Thus, when several lines are fed from a dynamo, the current values obtaining in each circuit are constant, and independent of the closing or opening of other circuits fed from the same source.

The foregoing examples assume identical resistance values for the various circuits fed from a common source of e.m.f. In those applications where the individual resistances of the various circuits fed from a common battery are not "evened up," it must be remembered that the current in a circuit varies directly as the electromotive force, and inversely as the resistance of the circuit.

Suppose, for example, that a 100-volt dynamo is employed to feed three circuits, the first having 1,000 ohms, the second 2,000 ohms, and the third 3,000 ohms resistance. By means of the formula given on page 84 for calculating joint-resistance, the joint-resistance of these three circuits would be 545 ohms. The total current strength in the joint circuit would equal

$$\frac{100}{545} = 183 \text{ m.a.}$$

and the portion of the total current traversing each branch may be ascertained thus:

$$\text{In } R_1,\ I = \frac{100}{1000} = 100 \text{ m.a.}$$

$$\text{In } R_2,\ I = \frac{100}{2000} = 50 \text{ m.a.}$$

$$\text{In } R_3,\ I = \frac{100}{3000} = \underline{33} \text{ m.a.}$$

$$183 \text{ m.a.}$$

MORSE SINGLE-LINE INSTRUMENTS

Figure 86 gives a view of a Morse key equipped with extension "legs" to be used in fastening the key on top of the operating table. This type of sending key, which is known as the "Bunnell steel lever key," is at the present time quite generally employed in commercial and railroad telegraphy. Its construction combines lightness of moving parts, durability, and ease of adjustment.

Figure 87 illustrates another form of the same type of key, designed to be fastened to the operating table by means of ordinary screw nails. In-

FIG. 86.—Bunnell key, "leg" type.

FIG. 87.

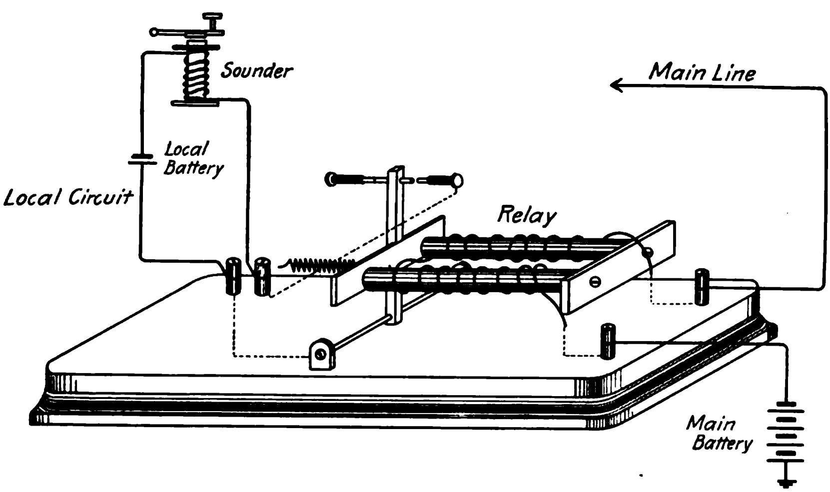


FIG. 88.—Morse relay, skeleton connections.

stead of the connecting wires being attached to "legs" as in the form of key illustrated in Fig. 86, two binding-posts mounted on the base of the key serve to hold the wires which connect the key into the circuit.

Figure 88 shows the binding-post and internal connections, both main line and local, of a main-line "relay" of the usual type. For the sake of

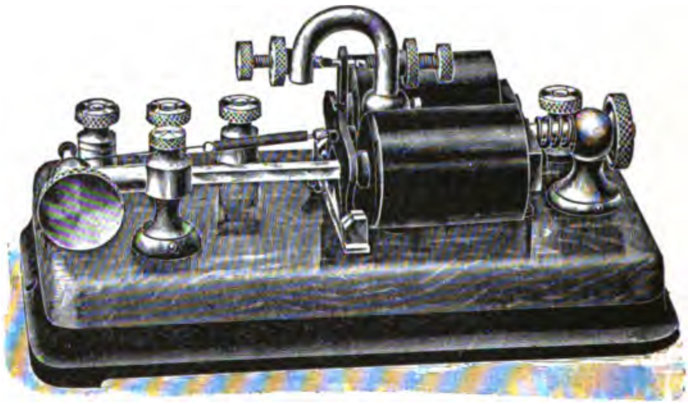


FIG. 89.—Morse relay.

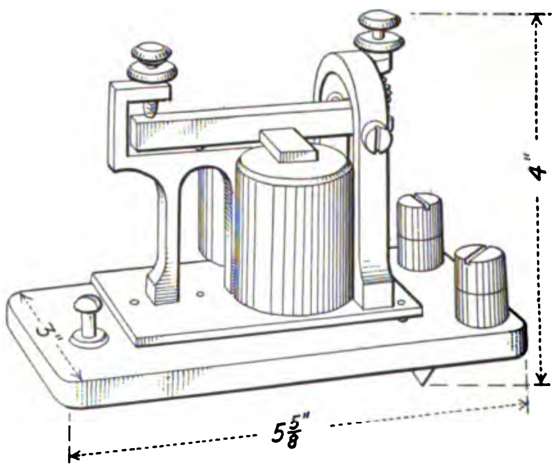


FIG. 90.—Morse sounder.

clearness, a few turns only of magnet wire are shown wound around the core of each spool. The way in which the movable armature tongue when attracted by the magnets connected in the main-line circuit closes the local circuit, thus operating the reading sounder, may easily be traced in the drawing.

Figure 89 shows a relay completely assembled, and Fig. 90 a view of a type of sounder extensively employed in this country.

CHAPTER VIII

LIGHTNING AND LIGHTNING ARRESTERS—FUSES—GROUND CONNECTIONS

For many years it was believed that lightning was simply an alternating current of very high frequency. During the past 20 years, however, a large amount of research work has been carried on with the object of learning something definite and conclusive in regard to the nature of lightning discharges, and it is now known that lightning may be manifested in several different ways.

A lightning disturbance may occur as:

A single discharge of very high potential.

As an alternating current of comparatively low frequency, having greater inductive than static effects.

As an alternating current of high frequency, having large capacity and high self-induction.

When lightning strikes a telegraph line, a part of the line may be destroyed due to the charge reaching the ground by way of the poles, the latter being split and torn as if from internal explosion.

When lines are provided with ground wires attached to poles and fixed close to the conducting wires, and with lightning arresters at terminals, the charge is divided, reaching the earth at as many points as are presented in the form of discharge-gaps. But even if the charge has been quickly drained off, its presence upon the conductor even for a brief interval of time affects the electric circuit so that a disturbance more or less pronounced is the result.

The single discharge of high potential, or the direct stroke as it is sometimes called, although rare in comparison with the number of disturbances due to electrostatic induction, is more disastrous to property. The immediate, or local effects of the direct flash include the shattering of glass or other insulators, splintering of crossarms and poles; incidental to the passage of the discharge to ground, as referred to above. The damage may be confined to a short section of the line, sometimes two or three pole lengths, or may extend over a distance of a mile. In most cases the severity of the damage decreases with the distance from the point at which the discharge takes place. The fact that beyond a comparatively short distance from the center of shock there is no visible damage to the line does not mean that the discharge has been completely dissipated, but rather that the current induced

in the conducting wire has after traveling an indefinite distance along the conductor become attenuated to an extent that robs the charge of its power to do further damage of the nature cited above. In the conductor, however, there has been started a current wave progressing outward which causes a surging likely to produce indirect disturbances at distant points in the circuit.

Analogous to the way in which a river may rise until dams and embankments give way, an induced charge of electricity mav accumulate in a circuit as a result of rain, snow, fog, or clouds of dust being driven across the line, until the difference of potential between line and ground assumes enormous proportions, and at the breaking-point discharges across lightning arresters attached to the line, and, seeking paths of least resistance, discharges to ground through the intervening dielectric.

If a positively charged cloud passes over a line, an electrostatic charge may be induced in which the earth below the line assumes a negative electrostatic charge. The line itself, due to its more elevated position, also takes on a negative charge, somewhat higher in potential than that of the earth. Of course, the sign of the charge on the conductor depends greatly upon the degree of insulation maintained between the line and the ground. As a positively charged cloud approaches a perfectly insulated line the latter may assume a positive charge at cloud potential, and as the potential rises with the approach of the cloud, the potential difference between line and earth may rise to a point where discharge takes place between the earth and the line. As the cloud recedes from the line, the latter then remains negatively charged and, inasmuch as this charge is no longer bound by the positive charge of the cloud, a discharge takes place from line to earth. When an electrostatic charge affects a line, there is a strain of contending forces—potentials at opposite polarities; naturally disruption takes place when these forces meet. The enormous strain manifested is not confined to the conducting wire or wires, but embraces all neighboring conductors or semiconductors, so much so that in certain instances persons standing 25 or more feet away from where the chief damage has been wrought have been severely shocked.

Undoubtedly the most frequent manifestations of atmospheric electricity in line conductors are the result of electrostatic induction from passing clouds. Each readjustment between cloud and ground or between cloud and cloud in the neighborhood of a conducting circuit brings about an abrupt alteration in the electrostatic charge on that part of the line immediately in the vicinity of the disturbance. The induced impulses in the circuit increase in strength and frequency as the cloud approaches the line and decrease as the cloud recedes.

The popular scientific conception of the conditions which exist in the atmosphere when an oscillatory discharge takes place assumes that the air, the cloud and the earth, in effect, constitute a huge condenser with the air as the dielectric. It is true, of course, that the dielectric in this case is con-

stantly varying in density, purity, and humidity, and this inconstancy of the insulating medium; in a measure accounts for the variegated effects observed. When the air breaks down under the strain and becomes heated to incandescence, the phenomenon observed is called lightning.

Many years ago it was discovered that a lightning discharge traveling through a conducting wire has, so to speak, an aversion to turning corners, insisting to its utmost upon traveling in a straight path. The excessive heating effects of these induced charges often deflagrate telegraph wires at points where the conductor has been injured mechanically (thus reducing its cross-section) or where the wire is "kinked" or bent. In the design of modern lightning arresters advantage has been taken of the fact that "kinks" or turns of wire serve to "choke" the induced oscillatory currents. Thus in several forms of arresters employed to protect aerial lines a choke-coil forms an important element of the arrester.

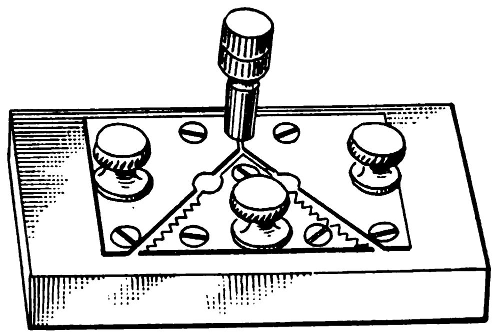


FIG. 91.—"Saw-tooth" lightning arrester.

The design of satisfactory protectors should provide against undue prolongation of abnormal currents in the conductor. This is accomplished by means of a properly designed "fuse." Also an air-gap or high-resistance path to earth should be provided for high-potential discharges. This may consist of two metal plates, one connected with the earth and the other with the line wire, one plate being provided with pointed "saw-teeth" as illustrated in Fig. 91. This lightning arrester is seldom seen except in the older installations.

Where it is required to guard against high potentials, it is customary to employ an arrester which offers, for large currents, a path to earth having a lower break-down point than is offered by the insulation of the circuit protected. Most protectors designed with this end in view consist of two conducting surfaces, one of which is connected to the line conductor and the other to the earth. The two sides of the arrester may be separated by a gap, either in open air or in a vacuum, or they may be separated by a high-resistance material such, for instance, as carborundum. The sensitiveness of a lightning arrester depends considerably upon the width of space separating the metallic or conducting elements of the arrester, and, although in practice arresters are employed having spacings of 0.005 to 0.010, and as high as 0.100 in., depending upon locality and character of protection, it is important that accurate spacing be maintained.

Figure 92 shows one form of arrester consisting of spring clips S and

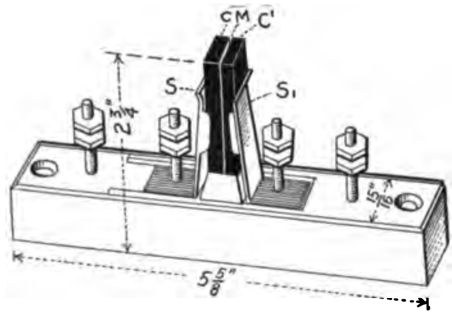


FIG. 92.—Carbon-block arrester.

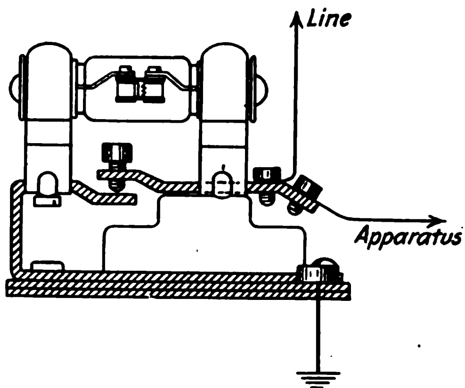


FIG. 93.—Vacuum-gap arrester.

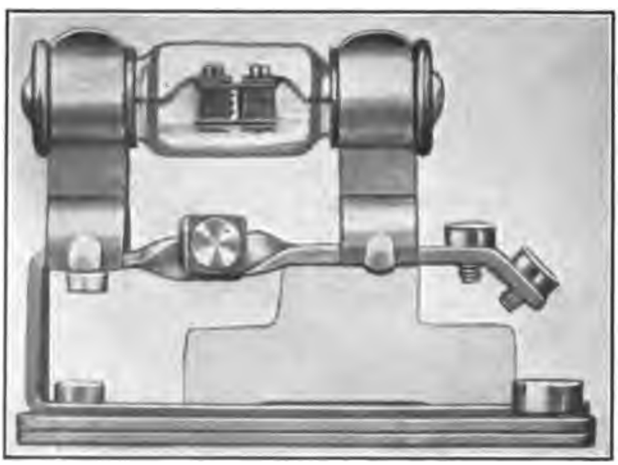


FIG. 94.

S_1, carbon blocks C and C_1, and separator M, the latter being made up of strips of mica to the desired thickness. The mica separator is perforated in several places, thus making as many air-gaps between the two carbon blocks, the latter being in contact with the spring clips which in turn are connected to line and ground respectively.

In this form of arrester it is of the greatest importance that a high grade of carbon be used in making the blocks, as the poorer grades are liable to "chip" or to oxidize and form carbon dust, and thus interfere with the correct spacing of the blocks.

Other forms of this type of arrester which have recently been introduced are the "vacuum gap" and the "Brach."

The former is shown diagrammatically in Fig. 93. In this make of air-gap arrester the discharge takes place in the form of a "brush" between two carbon plates separated by a partial vacuum. It is well known that an electrical discharge will take place between two conducting surfaces at a lower potential in a vacuum than in air at ordinary pressures. Thus, a greater separation of plates may be maintained when the discharge takes place in a vacuum.

The opposing surfaces of the carbon blocks—as in the original metal-plate arrester—are serrated, and there is no carbon dust produced which would form a deposit likely to reduce the insulation existing between the terminals of the arrester.

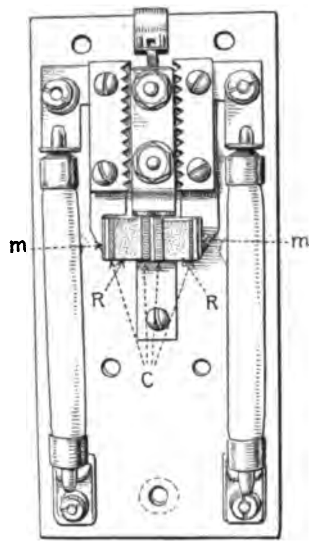


FIG. 95.—Combination saw-tooth and carborundum-block arrester.

Figure 94 gives a photographic view of the vacuum arrester.

In the Brach arrester a direct contact path from line to earth is provided through a high-resistance block which separates the metallic surfaces of the arrester. See Fig. 95.

The cut shows an arrester equipped with fuses and an auxiliary air-gap of the older form. The departure from the air-gap principle embodied in this arrester is illustrated at the lower extremity of the arrester elements and between the fuses, where M represents metallic plates, C, carbon plates, and R, blocks of a high-resistance compound. The cut shows a two-line unit.

The separator blocks used in this arrester have a resistance of about 4 megohms when subjected to a pressure of 240 volts, the resistance decreasing rapidly as the potential is increased.

Where arresters of the direct-contact type are distributed at intervals along a line, it is evident that the total insulation of the line will be somewhat

reduced, but where a high degree of insulation between line and earth is not essential, the "static" draining possibilities of this type of arrester may be of considerable advantage.

As a protection against oscillatory currents of high frequency and large self-induction, a "choke" coil may be included as an element of the arrester. A length of 2 or 3 ft. of insulated wire wound into a coil ½ or ¾ in. in diameter, when inserted in the line constitutes an effective barrier to the passage of high-frequency alternating currents. A well-known form of arrester which embodies the principles above referred to is that known as the Argus.

A well-designed form of choke coil as employed in guarding against lightning discharges is shown in Fig. 96, in which the conductor is carried through a spirally turned pipe of small diameter. The section of the

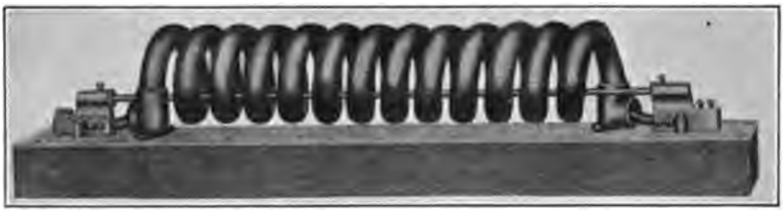


Fig. 96.—Lightning choke-coil.

conducting wire enclosed in the iron-pipe spiral is insulated, thus are combined two forms of impedance. The discharge-rod shown traversing the entire coil acts to carry off the static charge held back by the choke coil.

Lightning arresters connected with line wires; practically are condensers of small capacity, and in proportion to this capacity present conducting paths to earth for alternating currents.

After each lightning storm it is well to inspect all open-type carbon block arresters and to clean away any deposit of carbon dust which may have accumulated on the faces of the blocks or on the mountings.

LOCATION OF LIGHTNING ARRESTERS

Undoubtedly, the most desirable location for lightning protectors is outside of buildings, but owing to the close regulation practised and to the fact that the instruments and apparatus protected must be safeguarded from all high-tension currents extraneous to the buildings, it is customary to locate arresters inside the building.

Outside or "pole" arresters in various forms are used as additional safeguards, and it is good evidence of the efficiency of these external protectors that the number of instances are few where lightning and contact with high-tension circuits result in fire damage to buildings.

Figure 97 shows one method of attaching a lightning ground-wire to a

pole. With this arrangement a double-grooved insulator is required. The wire in contact with the ground is fastened along the length of the pole by means of staples, and at its upper extremity is twisted around the upper groove as shown on the right, the end of the wire being bent so as to form a

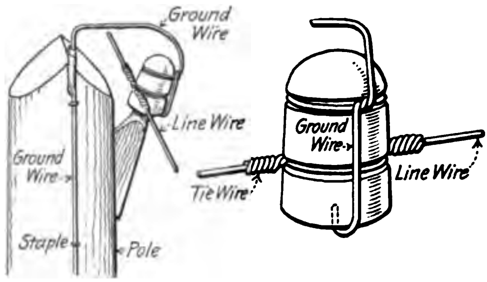


FIG. 97.—Pole arrester.

hook with which to clasp the bottom of the insulator. As shown on the left, a space, or air-gap, which may be regulated to suit the requirements, separates the tie-wire from the ground-rod.

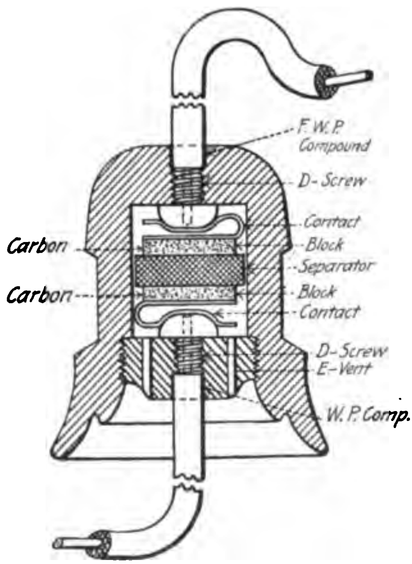


FIG. 98.—The "Brach" pole arrester.

A cross-section view of the Brach arrester adapted to out-door service is illustrated in Fig. 98. The manner in which this arrester is attached to the line wire is illustrated in the reproduction, Fig. 99.

When new lines are constructed, one telegraph company requires that:

"About 10 ft. of line wire be formed into a flat coil, and placed under the butt of the pole. The other end of the wire must be stretched up the pole and fastened thereto by twelve or more wire staples. It will be extended 7 in. above the top of the pole, and the end of the wire will then be turned back and fastened to the pole, making a projection above top of the pole 3 in. in length and doubled back, the said projection to be given three turns or twists."

Practice in regard to the spacing of lightning ground-wires along a line varies somewhat. One company requires that a ground wire be attached to every fifth pole, while another company requires that a wire be attached to every sixth pole on leads carrying from 1 to 12 wires, 35 poles per mile, and on lines carrying 12 wires or upward, with more than 35 poles per mile, the ground-wire must be attached to every tenth pole.

FIG. 99.

Fuses.—Protection of apparatus against abnormal currents, or currents of excessive strength, is usually accomplished by the employment of properly designed fuses.

In determinating the capacity of a fuse to be used in a given case, the principal points to be considered are:

1. The amount of current the fuse must carry continuously under normal working conditions.

2. The amount of current which the wiring or windings of the apparatus can safely carry during a certain period without undue heating.

3. The possible sources of trouble from foreign circuits carrying high potentials.

When these requirements have been determined with reasonable accuracy, the carrying capacity of the fuse may be decided upon. In every conductor

there is a point above which the temperature must not be allowed to rise, and the customary method of protecting against excessive temperature is to employ a fuse which has been designed to "melt" when that point has been reached.

Ordinarily, fuses consist of short lengths of wire composed of an alloy of lead and tin. The wire employed for the purpose may be of any desired diameter and length, its dimensions depending upon the degree of heat required to melt it when excessive currents flow through the conductor of which the fuse forms a part, during a given period of time.

The capacity of fuses used in telegraph circuits ranges from 1/2 to 10 amperes, with intermediate steps of 1 ampere, 2 amperes, and so on.

The half-ampere fuse generally employed will "blow" within two or three seconds after being subjected to a current of 1 ampere at 75° F.

Owing to variations in temperature in different parts of the country, between winter and summer seasons, it has not been found practicable to adjust the blowing point of 1/2-ampere fuses much closer than that indicated above. To adopt fuses of greater capacity than those named, for telegraph circuits, would place such circuits in the category of electric-light wires, which would be manifestly unreasonable, as the regular operating currents in telegraph circuits are infinitesimal when compared with the large currents carried in lighting circuits.

FIG. 100.—Enclosed fuse.

In the construction of fuses, several different types of fuse-link are used. These might be classified as "straight-wire link," "air-drum link," "flat link," "multiple-link," "cylinder link," etc.

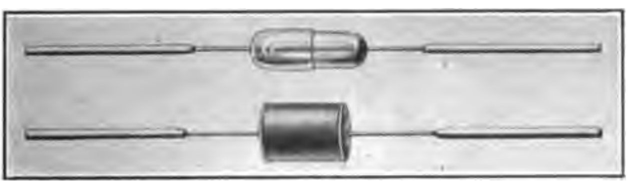


FIG. 101.—Air-drum fuse links.

The "enclosed" fuse, such as that illustrated in Fig. 100, consists of a pasteboard tube, containing a non-combustible filling, in the center of which is stretched the fuse-link, or wire, each terminal being securely connected with brass or copper ferrules affixed to the end of the tube. The straight-wire link consists simply of a short length of fuse-wire of uniform diameter.

In the construction of the air-drum link (Fig. 101) advantage has been

taken of the fact that the blowing time of a fuse may be rendered practically constant for any predetermined overload, regardless of the temperature of the filling, by enclosing a section of the fuse-wire in an air-tight casing.

In the simpler form of fuse the porous filling completely envelops the wire throughout its length, and it has been found that the blowing time varies considerably due to the fact that the material of which the filling consists dissipates the heat generated in the fuse-wire, which to an appreciable extent, makes the blowing time of the fuse dependent upon the temperature of the filling. The air-drum link is more regular in action, owing to the fact that the air space around a portion of the fuse metal permits of a more definite relation between the temperature of the fuse-wire and the current value in the circuit. The other types of fuse-link mentioned are modifications of the two described.

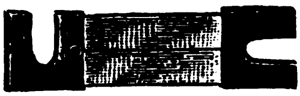


FIG. 102.—Mica enclosed fuse.

The filling used in packing the fusable element must be non-combustible, and preferably should be non-absorptive of moisture, chemically inert, porous, and have no tendency to solidify.

Figure 102 shows a form of "fuse" wherein a short length of fuse metal is enclosed between two strips of mica, the fuse element being stretched between two flat copper terminals which may be inserted between spring clips, or held fast by cross screws extending through the "slot" ends.

Figure 103 shows a convenient method of mounting a number of fuse units such as that illustrated in Fig. 102. When mounted in a box as shown, one terminal of each fuse is connected to a metal strip, which in turn may be connected with a battery or other source of e.m.f. while the other terminal of each fuse may be connected to any circuit required to be fed from that particular battery.

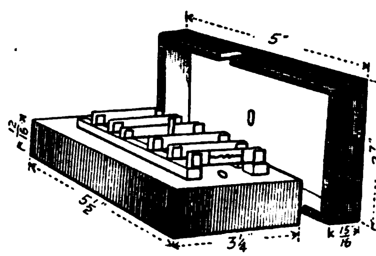


FIG. 103.—Box for mounting mica fuses.

Ground-wires, or Earths.—When a box constructed of insulating material such as dry wood, fiber, or glass is filled with earth, and the portion of earth thus isolated used as a section of an electric circuit, it is found that the resistance of the earth follows the same laws as that of any other substance, or the ohmic resistance of the isolated section of earth depends upon the character of the earth employed, the amount of moisture it contains, and upon its length and cross-section.

When two metal plates are buried in the earth, the resistance of that portion of the earth extending between them does not vary in the ratio of their distance apart as it does in the case of a portion of earth enclosed in an

isolated box. The resistance between two separated ground plates is dependent upon the character of the soil in the immediate neighborhood of each plate, upon the depth to which the plates are buried in the earth, and upon the size of plate used.

On account of the large surfaces exposed to the earth, water-pipes, and gas-mains make excellent "earth" connections. Where such pipes are not available, satisfactory ground connection can be had in moist earth or in a river which does not flow a long distance in a channel of rock. A sheet of zinc, or tinned copper, about $\frac{1}{16}$ in. thick and about 4 ft. square should be buried in a hole or trench, made deep enough to reach below dry sand or earth, and of rock. The bottom of the trench, which must be where the earth is always moist, should have a layer of coke about 2 ft. deep on which the metal plate is to rest, and above the plate should be deposited a layer of crushed coke about 2 ft. thick, after which the trench should be filled up with moist earth. Connection with the earth plate should consist of a hard-drawn copper wire of a size not less than No. 9 B. & S. gage, the earth end being soldered entirely across the surface of the ground plate.

When gas-pipes or water-pipes are used in place of buried earth plates, the connection should be made by wrapping a number of turns of the ground-wire around the pipe, thoroughly soldering the joint. Connections made to pipes should invariably be made on the "street" side of all service taps, to avoid as far as possible interruptions to the ground connection when changes or repairs are being made in the pipe systems.

CHAPTER IX

MAIN-LINE SWITCHBOARDS FOR TERMINAL OFFICES AND INTERMEDIATE OFFICES

At an office where a "one-wire" line terminates, the only circuit accessories required in addition to the signaling instruments are a lightning arrester, a line "fuse," and a "ground" connection. In order that the signaling relay may be "cut out," that is, disconnected from the line, during the absence of the attendant, or on any other occasion when such action might be desirable, it is usual to embody a "cut-out" feature in the lightning arrester and ground-switch unit. A simple form of this type of apparatus is illustrated in Fig. 91. This same device would answer all the requirements of an "intermediate" office on a single-wire line.

Where two or more line wires are cut into an intermediate office, or terminate at an office, then, in addition to the features above mentioned, a means must be provided whereby any two wires may be quickly cross-connected, or looped. Also a means should be provided whereby any one of the various line wires may be connected to any one of several sets of signaling instruments or to several sets of instruments at the same time.

From an operating standpoint, the importance of a telegraph office is closely related to the extensiveness of the switching facilities necessary to carry on the work of the office, and of the "wire district" in which the office is situated.

On account of the constantly changing conditions, it is rather difficult to classify telegraph offices in an order that would predetermine the apparatus required to equip any particular office. For general purposes, however, it is possible to gain a helpful understanding of the requirements in a given case, where offices are classified as follows:

Branch Offices, meaning, in a city, branches from the main office.

Way Offices, small intermediate offices, cut in on one-, two-, or three-way wires, operated simple Morse.

Intermediate Test Office.—An office on a trunk line having all through wires cut in for testing purposes.

Repeater Station.—An office on a trunk line where signals are automatically repeated, from one section to another on some or all of the wires connected into the office.

Terminal Station.—Offices located in large centers, where a considerable volume of local telegraphic traffic is handled, where messages are relayed

by hand, to other points, where automatic repeating facilities are available, and where "battery" is applied to main-line wires radiating therefrom.

A more extended classification would mean the subdivision of each of these classes into several grades, and the governing factors would include

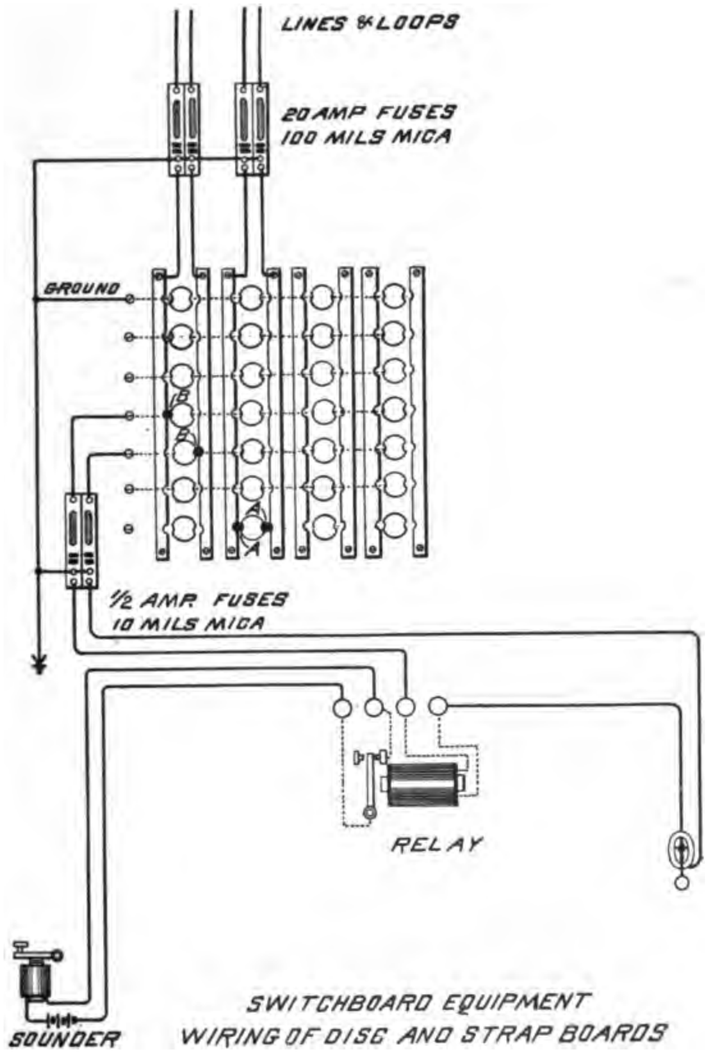


FIG. 104.

the amount of business handled, whether or not main-line wires take battery at the office, whether main-line testing is done from the office, etc.

Where the design of, and the operation of the switching apparatus are concerned, it is, of course, quite desirable to employ standard apparatus.

The continual improvement being made in the design and construction of switchboard equipment means that standardization and improvement must go hand in hand, and the benefits are best secured when improvements are introduced gradually throughout the entire system.

A type of main-line switchboard formerly known as the Universal, now generally referred to as the strap-and-disk board, has for many years been extensively employed at both intermediate and terminal stations.

Figure 104 gives a diagrammatic view of the electrical connections between line wires and office instruments where a strap-and-disk switchboard is used. Two separate line wires are shown "looped" into the office, both

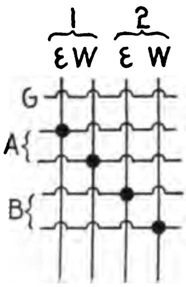


FIG. 105.

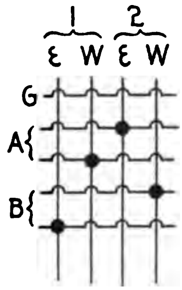


FIG. 106.

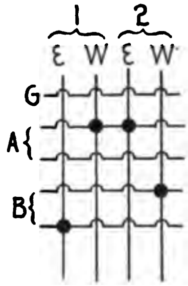


FIG. 107.

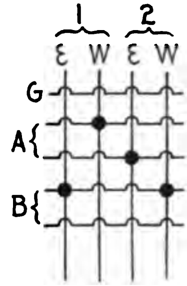


FIG. 108.

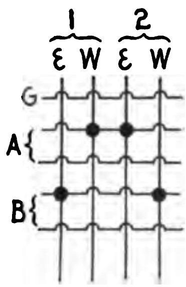


FIG. 109.

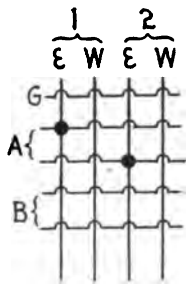


FIG. 110.

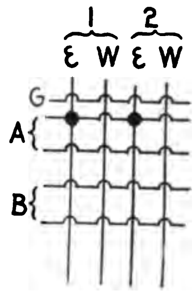


FIG. 111.

FIGS. 105 to 111.—Strap-and-disk switchboard combinations.

sides of each loop being connected through 20-ampere fuses, and to a lightning arrester having a separation between line and ground plates, of one tenth of an inch. It is evident that the "board" shown in Fig. 104 has accommodation for four through wires, that is, four line wires may be looped into an office having a board of this size.

The vertical elements or "straps" are connected with either side of a line, and each pair of straps in use represent one external circuit connected into and out of the office, while the horizontal elements, the disks (which are connected together in horizontal rows by means of metallic strips on the back of the board) are by way of binding posts connected through half-ampere

fuses, and lightning arresters having a 0.01-in. gap between plates, to signaling relays mounted on the operating tables.

Figures 105 to 111 inclusive show various combinations which may be made at an intermediate office, with two through circuits, extending, say east and west of the office.

Figure 105 shows the horizontal elements and the vertical elements of the switchboard, so connected by means of metallic "pegs" that each circuit is connected through the office, including in one circuit the signaling relay connected with binding posts *A*, and in the other circuit the relay connected with posts *B*.

Figure 106 shows wire No. 1 west "cross-connected" with wire No. 2 east, and wire No. 1 east with wire No. 2 west; each circuit so made up includes the windings of the signaling instrument wired to the terminals *A* and *B*, respectively.

If it is desired to eliminate the winding of the instrument connected with posts *A* from the circuit in which it is connected, all that is necessary is to place the two center pegs in the positions indicated in Fig. 107. Similarly, instrument *B* may be eliminated from the circuit as shown in Fig. 108, and both instruments may be cut out if the pegs are inserted as shown in Fig. 109. A horizontal row of disks is assigned to the ground connection *G*, and any wire may be "grounded" simply by inserting a peg in the hole at the intersection of the vertical strap connected with the wire to be earthed.

Figure 110 shows the disposition of the pegs when it is desired to "loop" wire No. 1 east with wire No. 2 east, allowing the instrument *A* to remain in circuit, or if it is not required to have the home instrument cut in, the pegs should be inserted as in Fig. 111. Switchboards of this type may be built large enough to take care of any number of wires. It is evident, of course,

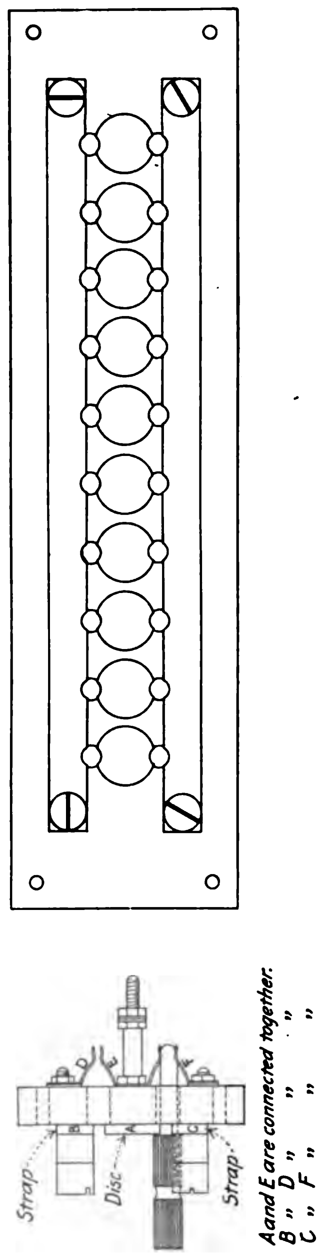


FIG. 112.—Improved form of strap-and-disk switchboard.

that as a board is enlarged to accommodate a large number of wires, its dimensions increase in both directions; that is, vertically and horizontally.

One difficulty experienced with the strap-and-disk switchboard is that the pegs are liable to work loose, and result either in a poor contact between

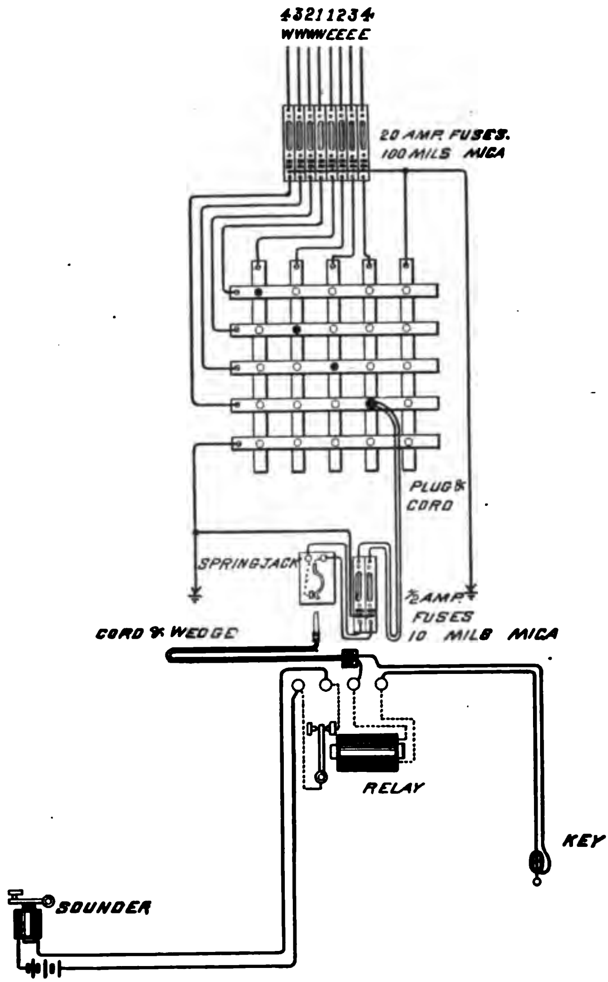


FIG. 113.—Cross-bar main-line switchboard.

strap and disk (thus introducing an abnormally high resistance into the circuit) or fall out entirely and interrupt the circuit. This difficulty is more often encountered in offices located in railroad depots where vibration caused by passing trains in time causes the pegs in the switchboard to work loose.

To avoid this annoyance an improved form of strap-and-disk board has recently been brought out (Fig. 112) the construction of which provides for a more positive union between peg, disk and strap. Instead of the tapered pegs usually employed, the improved board has a straight peg which goes through a hole drilled all the way through the slate or abestos board

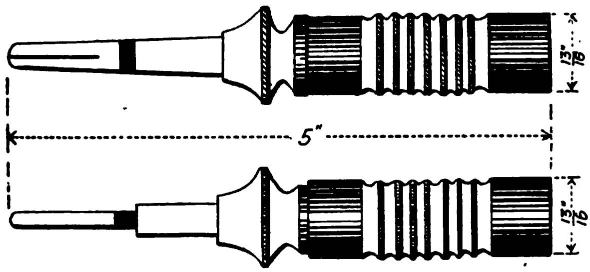


FIG. 114.—Double-conductor plugs for use with cross-bar switchboard.

base, and engages spring clips which are fastened to the backs of the disks and straps.

A form of switchboard known as the "cross-bar" board, in use at many offices, is illustrated in Fig. 113. In principle this form of switchboard is identical with the more common strap-and-disk board. All of the combinations possible with the latter may be made with the cross-bar arrangement. The only noteworthy difference being that the home relay is connected into the desired circuit by means of a "double-plug," which completes the circuit from horizontal strip through the double-conductor cord and back to the vertical strip. When it is not required to have the home relay in circuit, a solid plug is inserted in place of the double-plug. The diagram, Fig. 113, shows the fuse, lightning arrester, and ground connections, also the connections of the main-line and local instruments required in connection with this type of switchboard.

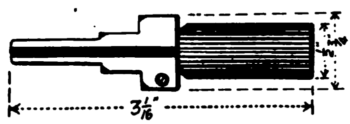


FIG. 115.—Split plug for use with strap-and-disk switchboard.

It is evident, too, that for a given number of vertical straps, the cross-bar form of switchboard will accommodate twice as many lines connected through an intermediate office as will the strap-and-disk board, owing to the fact that the lines in one direction are connected to the vertical straps and the lines in the opposite direction to the horizontal straps, or bars.

Figure 114 illustrates the form of double plug used with the cross-bar board to cut in a set of instruments. The cord used in connection with this plug is a flexible double conductor, one conductor being connected with the "tip" of the plug, while the other is connected with the metal portion of the plug back of the hard-rubber insulating strip.

The strap-and-disk board, also, may be connected so that the lines extending in one direction will be attached to the binding-post terminals of the horizontal elements, while the lines in the opposite direction will be attached to the vertical straps. When this is done, a "split-plug" of the form shown in Fig. 115 is used to cut in a set of instruments at the home station. Where switchboards are wired in this way, it is necessary to have one or two spare

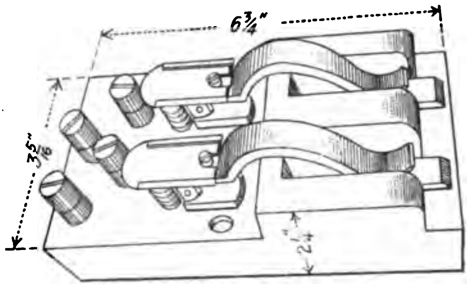


FIG. 116.—Double porcelain base spring-jack.

horizontal and as many spare vertical straps in order that line wires may be "looped" when required.

The unit type of strap-and-disk switchboard illustrated in Fig. 112, in connection with the spring-jack arrangement shown in Fig. 116, has within recent years been introduced for the purpose of meeting the need for a more flexible and rapid switching system.

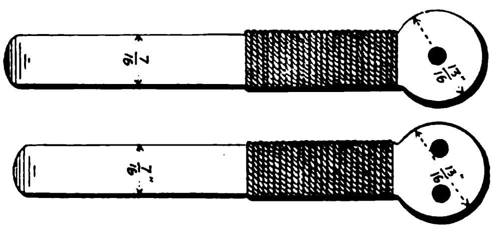


FIG. 117.—Single and double conductor wedges for use with spring-jacks.

The "wedges" (Fig. 117) used in connection with spring-jacks to make the various combinations of circuits required in practice are made up either as single conductors or as double conductors. The "single" wedge has a length of flexible single-conductor cord attached to a brass strip on one side of the wedge, the other side of which is of hard rubber, while the "double" wedge has a brass strip on each side, separated by an insulating strip of hard rubber. Each of the metal strips has connected with it one of the conductors of a flexible twin-cord.

The spring-jack, permitting as it does of the insertion of several wedges

in various relations to each other, provides an excellent means of meeting main-line telegraph switchboard requirements.

Figure 118 shows a front and a side view of one unit of the arrangement referred to. The line wires are shown entering through the "fuse" and

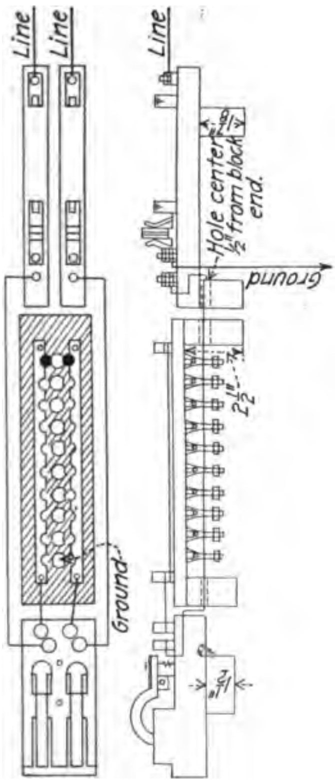


FIG. 118.—Front and side views of switchboard unit including strap and disk, and spring-jack connections.

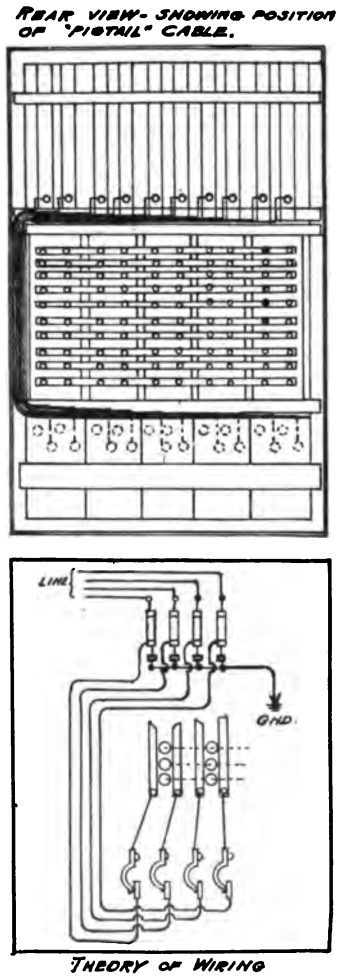


FIG. 119.

lightning protector, from there connected to the inside or stationary element of the spring-jack, the spring-actuated, or movable element (the shank) of which is in turn connected with a vertical strip of the switchboard proper.

Figure 119 shows the back-of-the-board wiring of a five-line intermediate

switchboard of the strap-and-disk type equipped with spring-jacks. It may be noted that the connecting wires leading from the office side of the protective device to the heel of the spring-jack, are "cabled" instead of being brought down separately as shown in Fig. 118. The lower portion

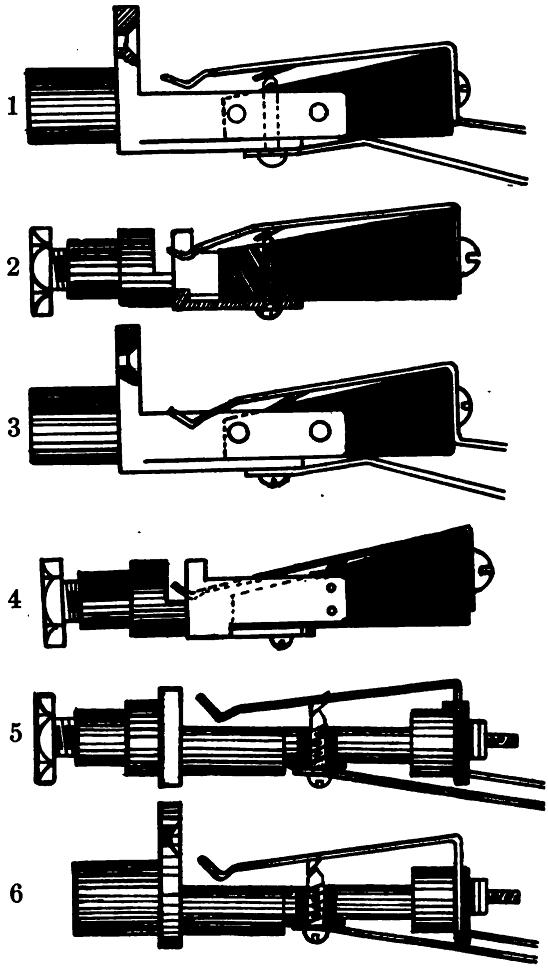


FIG. 120.

of Fig. 119 plainly shows the theory of the connections of this convenient switching arrangement.

One of the advantages of the unit type of board is that the switching facilities of an office may be increased to take care of additional lines, simply by adding additional units to the existing switchboard.

Several years ago telegraph engineers recognized the possibilities of the

telephone type of jack (the pin-jack) for telegraph purposes, and the pioneer work along this line, done by Mr. J. F. Skirrow, Associate Electrical Engineer of the Postal Telegraph-Cable Company, New York, has resulted in the development of a line of switching apparatus which embodies all of the advantages of this compact and useful device. Pin-jacks are made to meet various requirements, and are known as "open-circuit jacks," "closed-circuit," "patching," "grounding," "series," "multiple" jacks, etc. In construction, several of these forms of jack are identical, but the different forms are variously designated as stated.

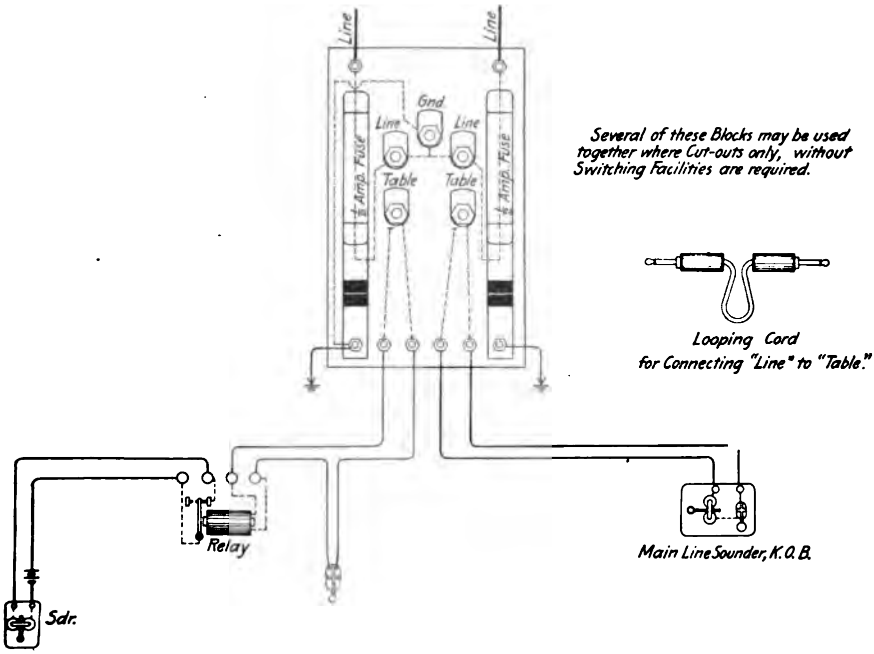


FIG. 121.

Figure 120 shows several styles of pin-jack, each designed to meet a different requirement. If in each case the dark sections are regarded as consisting of insulating material, the uses to which each may be put is self-evident. No. 1, for instance, is a series or closed-circuit jack intended for use in a wooden shelf. No. 2, a series or closed-circuit jack for use in a porcelain block. No. 3, an open or multiple-jack for use in a wooden shelf. No. 4, an open jack for mounting in a porcelain block. Nos. 5 and 6, patching jacks for mounting in wood and porcelain respectively.

Figure 121 shows a switch "block" having the line and instrument circuits connected through pin-jacks. The pin-jacks are mounted in a porcelain block on a common base with the fuse holders and the lightning arresters.

Figure 122 shows the theoretical connections of the five pin-jacks. It will be seen that the two "line" and two "table" jacks are of the closed-circuit or series type, while the grounding-jack is of the open-circuit type.

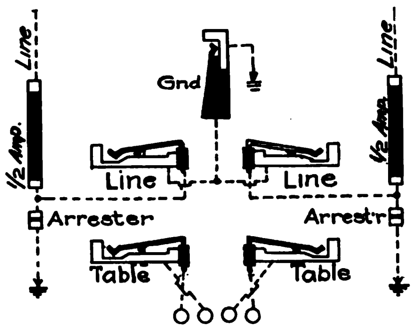


FIG. 122.—Connections of the five pin-jacks mounted in the switch block, Fig. 121.

The insertion of a solid metal plug in the grounding-jack connects the line wires to "earth" on the ground side of either line-jack, while the insertion of double-conductor plugs (shown on the right in Fig. 121) in either of the line-jacks connects the line in series with whichever table-jack the double plug on the other end of the flexible cord may be inserted into.

The main-line instruments in the office are permanently wired to the binding-posts on the lower edge of the switch-block, the binding-posts, in turn, being connected with the table-jacks.

It is evident that provision is made for operating one or two main-line

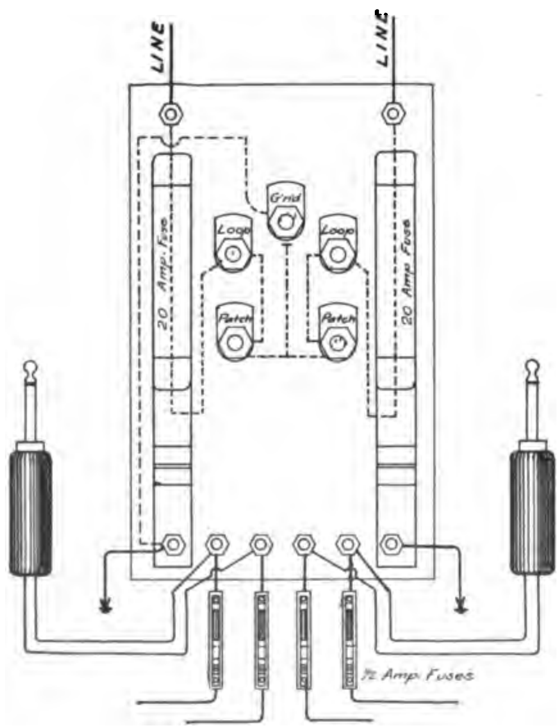


FIG. 123.—Switch block equipped with cross-connecting facilities.

instruments upon a "loop," and also for "splitting" or dividing the loop into two single grounded circuits, the latter being accomplished by the insertion of a solid metal plug in the ground-jack.

This switching arrangement, however, cannot be used where cross-connecting facilities are required.

As a branch office "cut-out" this arrangement meets the requirements admirably. When the office instruments are to be cut out at night, the only operation necessary on the part of the attendant is to withdraw the plugs from the pin-jacks.

A switch-block similar to the above in construction and appearance, but having facilities for cross-connecting wires, is depicted in the diagram, Fig. 123.

Intermediate switchboards intended for several wires may be made up by assembling a number of these units.

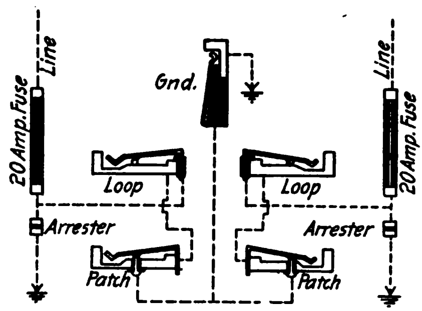


FIG. 124.—Connections of the five pin-jacks mounted in the switch block, Fig. 123.

To ground a wire in either direction, a solid metal plug is inserted in the ground-jack. Cross-connections are made by means of flexible conducting-cords having solid metal plugs on each end. One plug is inserted in the patching-jack of one wire and the other plug in the patching-jack of the other wire, east or west, north or south, as desired.

To test a patch by grounding the line, one plug of a patching-cord is held in contact with the ground-post below the lightning arrester, while the other plug is held in contact with the line wire where it enters the fuse. The office instruments may be cut in through the looping-jacks by means of the double-conductor cords and plugs shown on the right and left, Fig. 123.

Figure 124, shows theoretically the connections through the various jacks.

These switch-blocks are fire-proof and practically indestructible.

In most of the offices of the Western Union Telegraph Company, and in the majority of railroad offices throughout the United States and Canada, the strap-and-disk switchboard is used at intermediate offices. In the offices of the Postal Telegraph-Cable Company, as well as in the railroad offices operated in connection with the Postal Company's system, although there are a large number of strap-and-disk switchboards in use, the pin-jack type of switch is extensively employed, and such equipment is regarded as standard.

At intermediate offices having not over six main wires, the "Postal"

employs a switching system made up as shown in Fig. 125. In the diagram is shown all necessary circuit equipment for six through wires. The view at the top shows the course of the circuit from where the line wire enters from the west through the pin-jack contacts and fuses to the point where the line east leaves the office.

The lightning arrester and fuse equipment in each case is mounted on separate porcelain blocks. Also, the six pin-jacks are mounted in a porcelain block. Thus each wire connected into and out of the office passes through a three-block unit consisting of two fuse and arrester blocks and a pin-jack block. Two of the jacks are looping-jacks, one to cut-in east, the other to cut-in west. Two of the jacks are patching-jacks east and west,

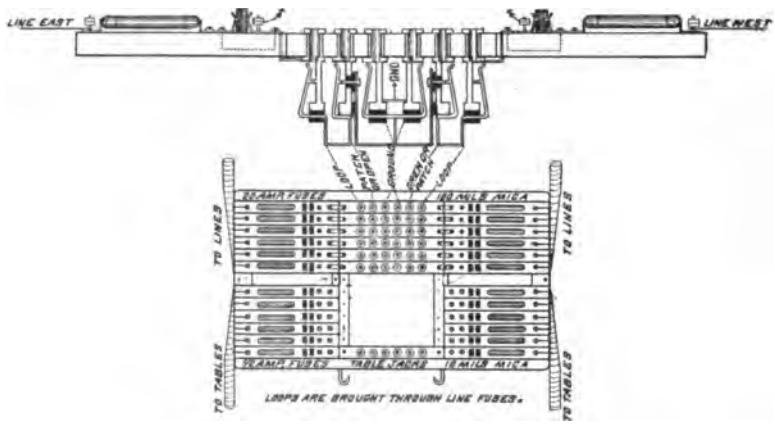


FIG. 125.—Pin-jack switchboard equipment for offices having not over six lines.

and the remaining two are grounding-jacks east and west. Where this type of switchboard is used, the following directions apply to its operation:

To Cut in or Loop an Instrument upon a Wire.—Place the instrument plug in one of the jacks of the wire it is desired to loop into, under the word "loop" in the brass guide plate.

To Open a Wire.—Place a solid plug in the jack of the wire it is desired to "open" under the words "open or patch" in the guide plate.

To Ground a Wire.—Use the same plug as for opening, but place it in the jack under the word "ground" in the guide plate. If a grounding-plug and an opening-plug are used upon the same side of a wire at the same time, the wire will be opened upon that side and grounded upon the other. Looping, opening or grounding may be done north, south, east or west according to which jack of the two provided for that purpose is used, in accordance with the marks on the guide plate.

To Patch a Wire.—Use a cord with a solid plug on each end. If it is desired to patch No. 1 west to No. 2 east, place one plug in the jack No. 1 west

under the words "open or patch" in the guide plate and the other plug in the jack No. 2 east under the words "open or patch." All other patches are made in a similar manner.

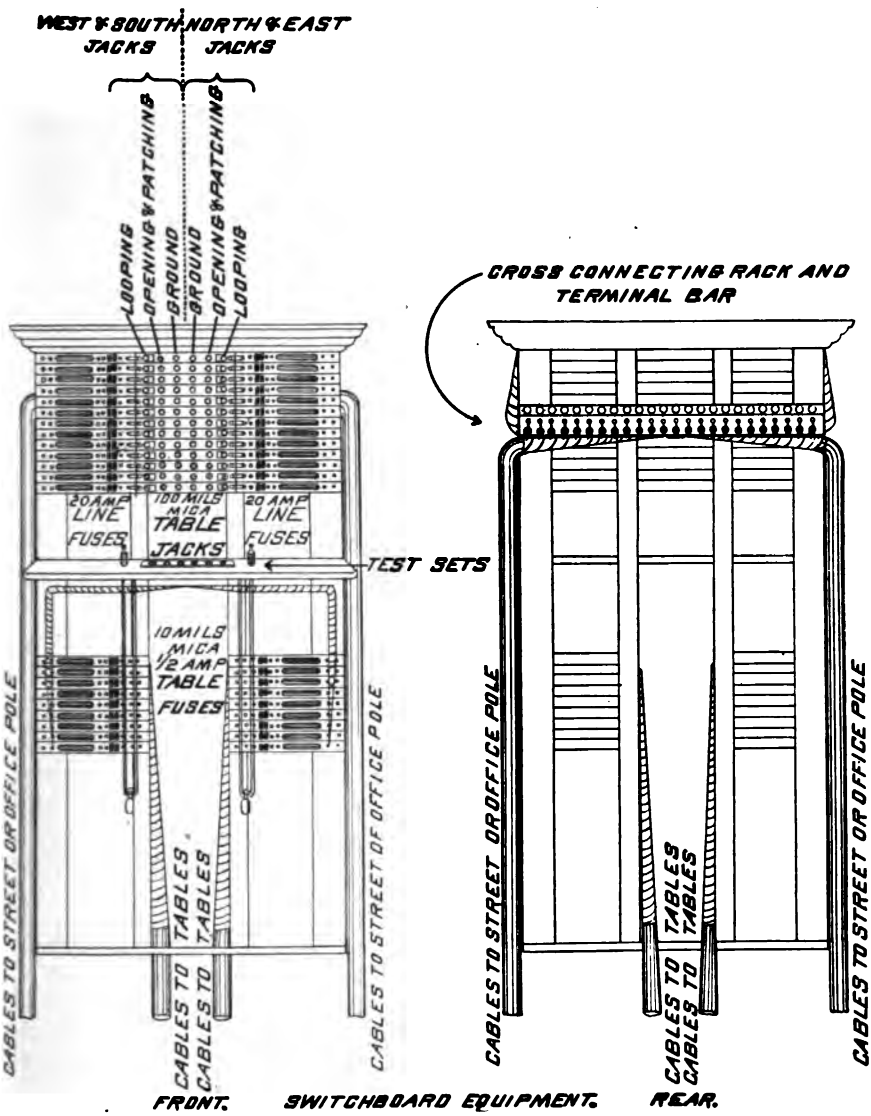


FIG. 126.—Pin-jack switchboard for offices having six or more through wires.

To Connect a Loop into a Main Line.—Loops are brought to the switchboard in the same manner as line wires, that is, one side of the loop comes in at each side of the board. Use a double-cord with a double, or "looping"

plug on each end. Place one plug in a jack of the loop under the word "loop," and the other plug in a jack of the line under the word "loop." Another method: use single cords and patch one side of the loop to one side of the line, and the other side of the loop to the other side of the line, using the patching jacks as explained under "to patch a wire." When necessary to place more than one loop upon the same line, connect the loops together, using a double-cord from a looping-jack of one loop to a looping-jack of the other loop. Then connect the line to one of the loops as described above.

When an attendant is asked to ground a wire "out side of the board" for a test, the procedure outlined in connection with Fig. 123 for "testing a patch by grounding the line" may be followed.

All of the "fuse" and switchboard connections of a wire can be "bridged" out (to test fuses, jacks, etc.) by using a single cord, placing one plug against each of the line terminals at the fuse blocks.

A double plug attached to a double-conductor cord connected with the office instrument is inserted in a looping jack when it is desired to cut the instrument in circuit.

At intermediate offices having six or more through wires, in those instances where pin-jack equipment is used, the fuse and arrester blocks, pin-jack blocks, etc., are mounted on an angle-iron frame of substantial construction and finished appearance as indicated in Fig. 126.

The circuit connections are, of course, identical with those shown in the smaller switchboard, Fig. 125. To the larger board there is added a "terminal bar," and a cross-connecting rack, mounted on the back of the switchboard as shown on the right, Fig. 126. These additional features make possible a systematic distribution of cable conductors and provide means whereby cross-connections may be made between the line wires on the back of the board when so desired.

TERMINAL OFFICE SWITCHBOARD EQUIPMENT

The highest development in switchboard construction is found at the larger terminal stations, where on account of the large number of lines to be cared for, it is necessary to employ thoroughly systematized methods of circuit identification, and to provide facilities for making alterations and additions to the wire plant in such a manner that regular service will not be interrupted.

Figure 127 shows an arrangement of fuse and arrester equipment at a terminal office. The line wires from the aerial or underground cable are shown coming from the street in a cable. Each line wire has a circuit through one of the terminal blocks, to the cable which leads to the cross-connecting frame shown on the left. Usually the terminal frame shown on the right is

located as near as possible to the point where the cabled line wires enter the building. The terminal bars mounted in this frame consist of porcelain blocks, each one of which has mounted in it four pin-jacks as shown in outline

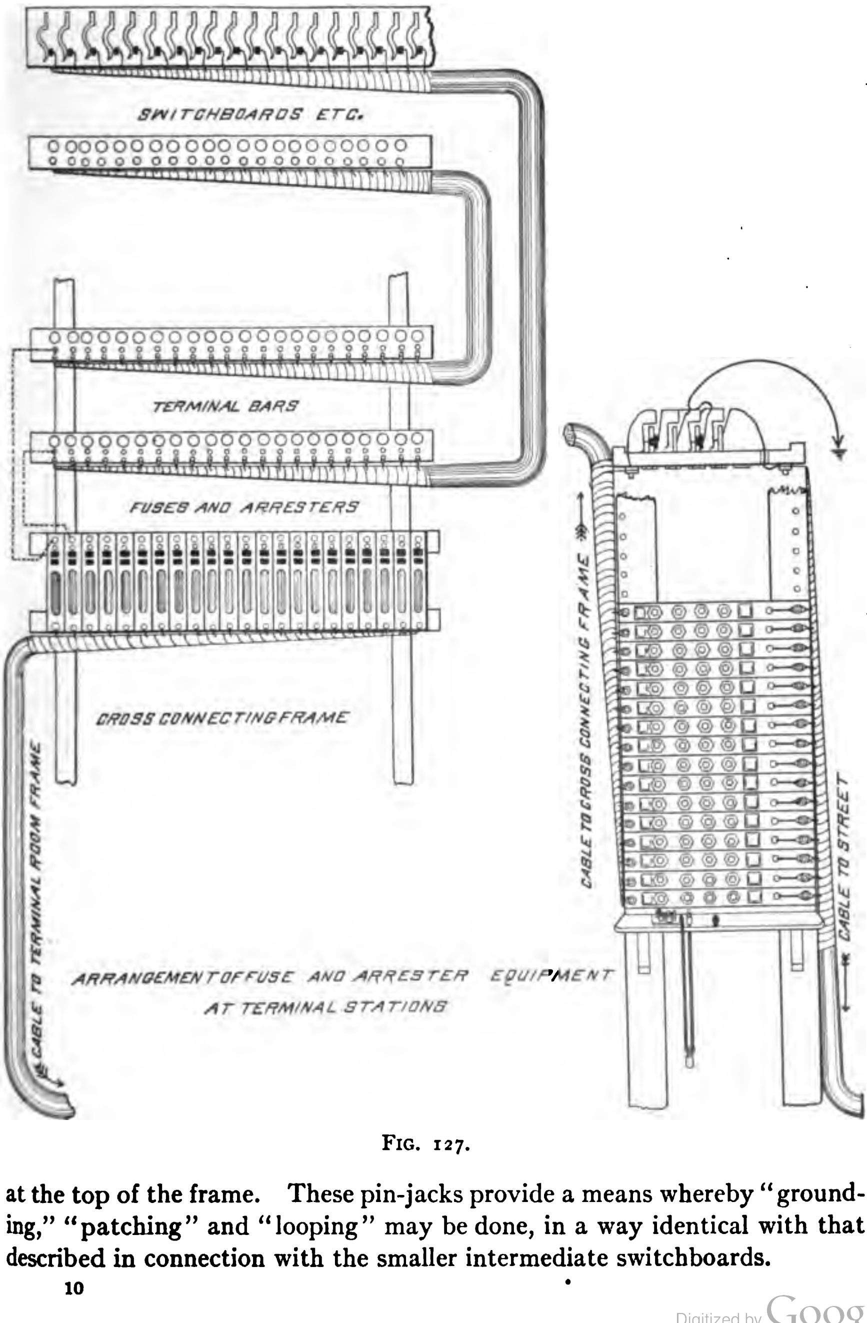
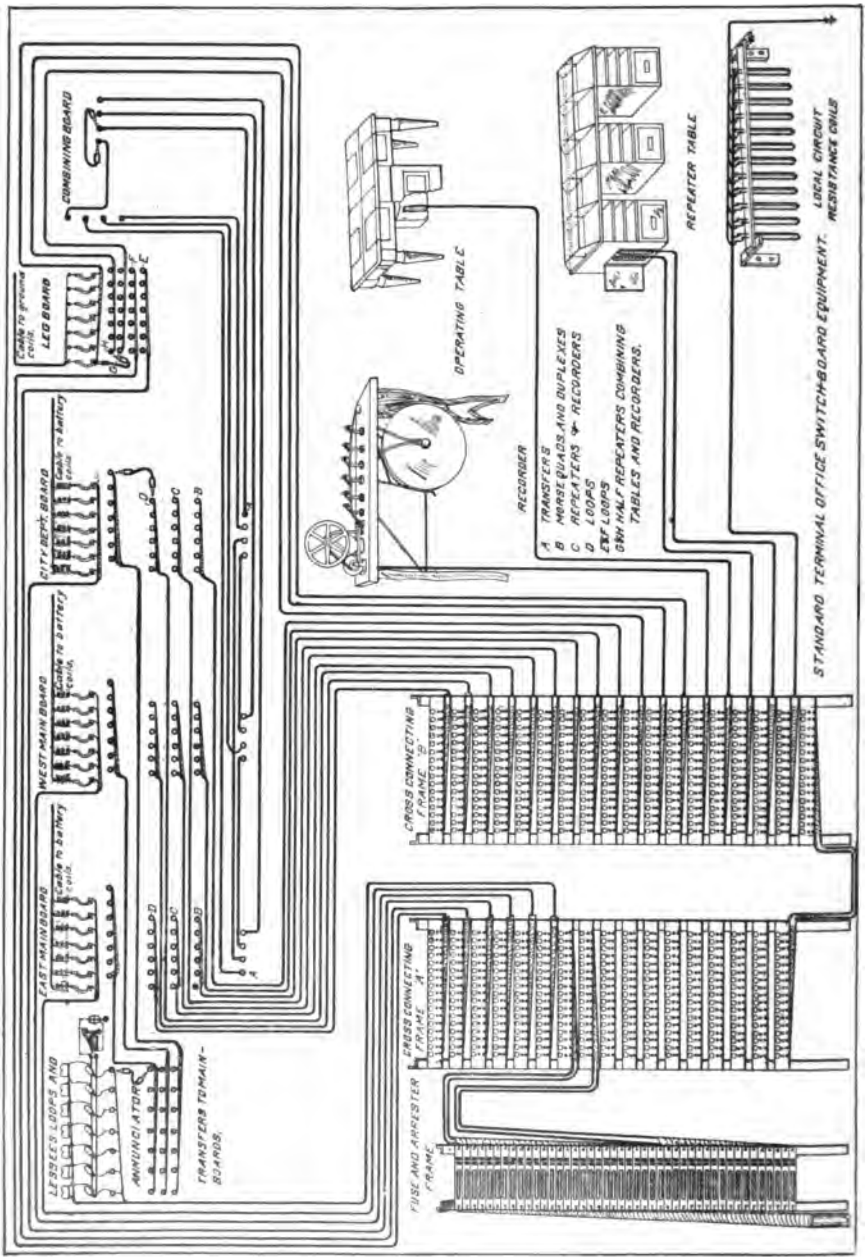


FIG. 127.

at the top of the frame. These pin-jacks provide a means whereby "grounding," "patching" and "looping" may be done, in a way identical with that described in connection with the smaller intermediate switchboards.



STANDARD TERMINAL OFFICE SWITCH-BOARD EQUIPMENT.

FIG. 128.

The cross-connecting frame shown on the left is located in close proximity to the main switchboard in the operating room; generally it is convenient to mount the frame immediately in the rear of the switchboard.

A more complete plan of the wiring between the point where line wires are brought from the terminal room to the fuse and arrester frame in the rear of the switchboard proper, and the cross-connecting frame, is shown in Fig. 128. The arrangement of conductors from cross-connecting frames to pin-jacks and spring-jacks in the main switchboard and from cross-connecting frames to instrument tables is clearly shown in the diagram. The pin-jack locations *A* provide a means for transferring circuits from one section of the main board to other sections. All of the connections are made with flexible conducting cords the terminals of which are equipped with single or double plugs, single or double wedges as required.

The terminal room equipment is in reality a switching system, practically a duplicate of that installed in the main operating room, but constructed with the object of providing for flexibility and utility rather than for fine appearance. The advantages of having a complete switching system close to the point where the lines enter the building from underground and aerial cables are that the jacks in the terminal room frame serve both for cable terminals and for temporary cross-connecting purposes by means of cords when cables are in trouble. From this frame may be made quick tests of cable interruptions, and the equipment may be used as a temporary switchboard in case the main switchboard in the operating room should be destroyed by fire or disabled from any cause.

The function of the cross-connecting frame mounted in the rear of the main switchboard is to act as an intermediate connection between the pin-jack and spring-jack connections of the switchboard and the instruments located on operating tables.

In the offices of the Postal Telegraph-Cable Company all frames are of angle-iron, including switchboard frames and all switchboard connections, cross-connecting frame, and terminal frame connections are mounted either upon slate, porcelain, or asbestos board.

CONDUCTORS BETWEEN CROSS-CONNECTING FRAMES AND OPERATING TABLES

All of the conducting wires required between cross-connecting frames and instrument tables, and between the power switchboard and instrument tables are, in all up-to-date installations, carried through floor ducts or trenches.

The trenches are from 4 to 8 in. wide and of about the same depth, and, as usually arranged, have a conveniently removable cast-iron top or lid, laid flush with the surface of the floor. In this trench are laid all of the battery

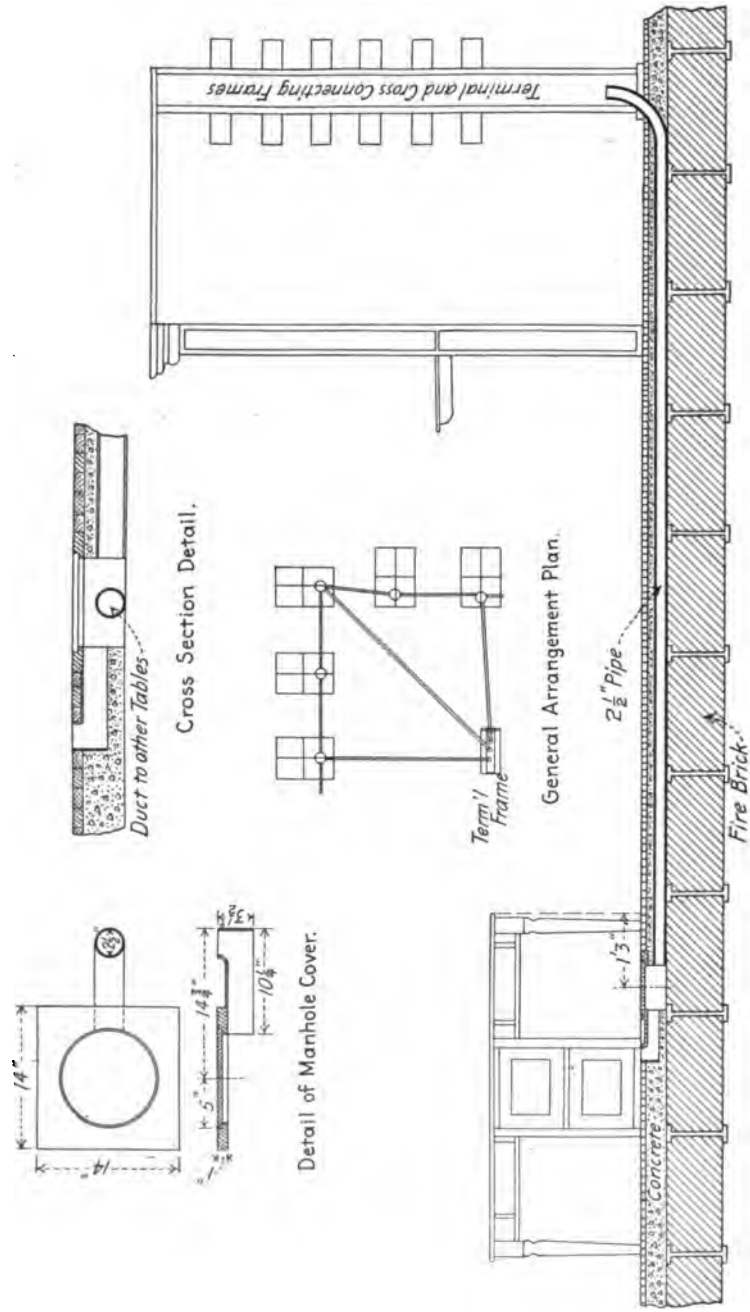


FIG. 129.—Floor duct cable distribution between cross-connecting frame and instrument tables.

wires and cables leading from the cross-connecting frames to the various operating tables.

In some instances, instead of using open top trenches, iron pipes 2½ in. in diameter are embedded in concrete flooring and so distributed that all parts of the operating room are served as indicated in Fig. 129. The diagram shows a skeleton main-line switchboard with cross-connecting frame in the rear. An iron-pipe conduit is shown laid beneath the office flooring and stretching from the wiring frame to an operating table, there terminating in a hand-hole with surface outlet under the table. From the hand-hole a

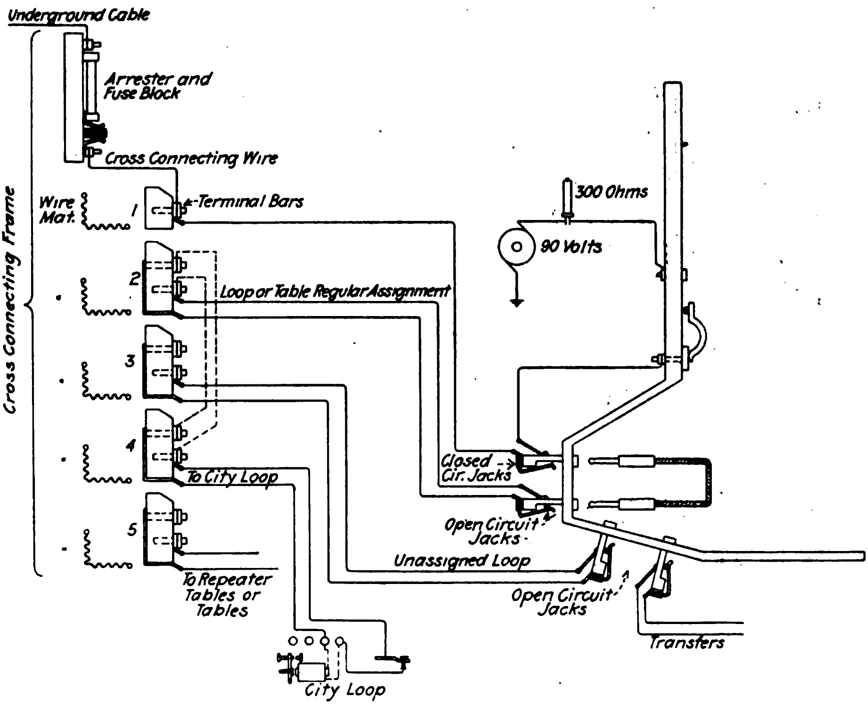


FIG. 130.—Line wire connections between underground or aerial cables and main-line switchboard at a terminal office.

short lateral duct provides access to the instruments mounted on top of the table through a wire chute situated between the type-writer lockers.

In the more recent installations a wiring cabinet has been built into the aisle end of each operating table, the hand-hole outlet from the floor duct being built in the floor within the cabinet. This latter arrangement provides for accessible mounting of all fuses, resistance coils, cable terminal strips, etc., constituting that part of the equipment of the table.

The plan and construction details shown in Fig. 129 are self-explanatory.

That portion of the wiring of a terminal office between the cross-connecting frames and the switchboard, so far as main-line wires are concerned, is shown in Fig. 130.

The course of a line wire from the aerial or underground cable may be traced through the line fuse, lightning-arrester block, cross-connecting wire to terminal bar, thence through a closed-circuit or series pin-jack to the spring-jack mounted on the face of the main switchboard. If the main-line wire shown is regularly assigned to a particular service, the connection is made by means of a short flexible cord with plug terminals, the plugs being inserted in the pin-jacks as suggested in the diagram. The employment of short cords for regular circuit assignments greatly reduces the amount of conducting cord necessary to make a given number of connections.

FIG. 131.—Sections of a main-line switchboard at a terminal office.

If the line wire shown were required to be transferred to a distant part of the board, the plug on one end of the cord would be inserted in the closed-circuit jack, while the other plug would be inserted in one of the transfer-jacks leading to that section of the switchboard where the connection is desired.

Figure 131 shows two sections of a large main-line switchboard built up of slate panels mounted on angle-iron framework. From the circuit diagrams heretofore shown, the reader will recognize the strap-and-disk arrangement, as well as the spring-jack and pin-jack equipment mounted underneath.

NEW WESTERN UNION SWITCHBOARD EQUIPMENT

In new construction, and in the reconstruction of switchboard equipment, the Western Union Telegraph Company plans to make extensive use of the

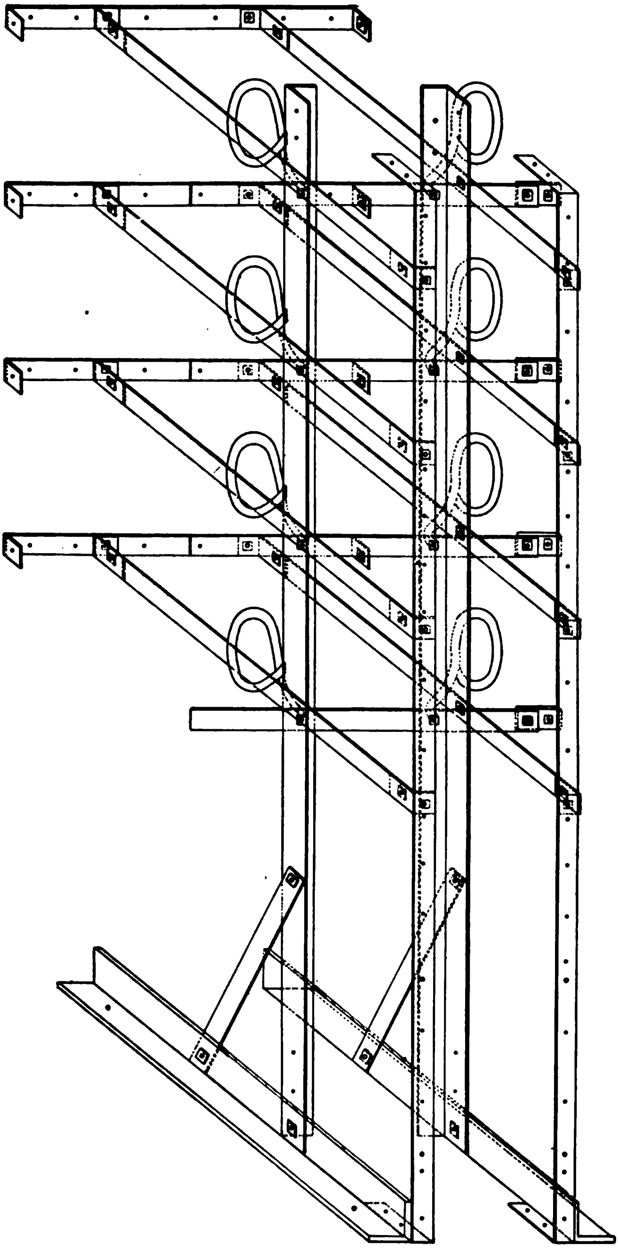


FIG. 132.—Western Union distributing frame.

pin-jack. The aim is to abandon the use of the strap-and-disk equipment, also the spring-jack and wedge accessories now universally employed for main-line switching purposes.

The new type of switchboard consists of an angle-iron frame, having mounted on its face porcelain panels, each panel containing 16 telephone-type pin-jacks, similar to those previously illustrated and described.

A switchboard containing ten panels will have 160 pin-jacks, and where four jacks in series are required to take care of the various operations of "grounding," "looping," and "patching," a 10-panel board will accommodate 40 main-line wires.

DISTRIBUTING FRAMES

In new installations, the Western Union Company consolidates the "terminal room," and "cross-connecting" frame, features as utilized in the "Postal" Company's service, forming a common "distributing frame" of the type employed in telephone service.

Figure 132 shows a perspective view of a section of the distributing frame, which is located near the main switchboard. All line wires cabled into the office from underground or aerial lines are brought directly to the distributing frame as also are all cables from instrument tables, the various house circuits being completed by means of short cross-connecting wires extending through the frame. The terminal block units for mounting on the frame are made of porcelain, each block having 10 wing-nut binding posts.

The distributing frame as a whole is made up of "base units" and "top units." The illustration, Fig. 132, is that of a base unit.

Both sides of a standard base unit will accommodate 24 terminal blocks, and both sides of a standard top unit, the same number.

The function of the distributing frame is identical with that of the cross-connecting frame previously described, that is, to provide means for making any required connection between the different sets of instruments in use, or between line wires and signaling instruments mounted on operating tables, without interfering with the cabled conductors, or disturbing the permanent wiring of the switchboard proper.

CHAPTER X

ELECTRICAL MEASURING INSTRUMENTS

TELEGRAPH LINE AND CIRCUIT TESTING

The satisfactory operation of telegraph circuits is almost entirely dependent upon the efficiency of the methods of testing practised, upon thoroughness of inspection, and upon the standards of line maintenance observed by the operating department of a telegraph administration.

From the beginning of the art and until a comparatively recent period, the Tangent Galvanometer was used almost exclusively for the purpose of making tests and measurements. In recent years, however, the quickening of the service has created a demand for more rapid methods of circuit testing, and at the present time the direct-reading instruments, such as the voltmeter, ammeter, and milammeter, are entensively employed in telegraph testing. Even the Wheatstone bridge, so long the standard measuring instrument, is now used only where accurate figures are necessary.

The demands of fast service are such that modern practice recognizes the value of qualitative as distinguished from quantitative measurements; so much so that we find the simple telephone receiver gaining favor as an indicator of faults. True, the great growth in the practice of cabling conductors has created conditions favorable to the employment of the telephone receiver as a fault finder.

In what follows, various practical and laboratory methods of making all tests and measurements required in practice are explained in sufficient detail to enable the practical telegrapher to familiarize himself with the procedure customary in each case.

The Galvanometer.—The term galvanometer might correctly be applied to any indicating instrument which measures the magnitude of, or indicates the direction of electric currents.

While there are many makes of galvanometer in use, practically all such instruments are either of the moving-coil or moving-needle type.

The former is known as the d'Arsonval type of instrument, in which a small coil of wire is suspended between the poles of a magnet, with its axis normally at right angles to the lines of force in the magnetic field.

The moving-needle instrument has a magnetized steel needle or pointer delicately suspended with its axis horizontal, and having a movement in a horizontal plane. Normally the indicating needle points in a north and

FIG. 133.—d'Arsonval portable galvanometer.

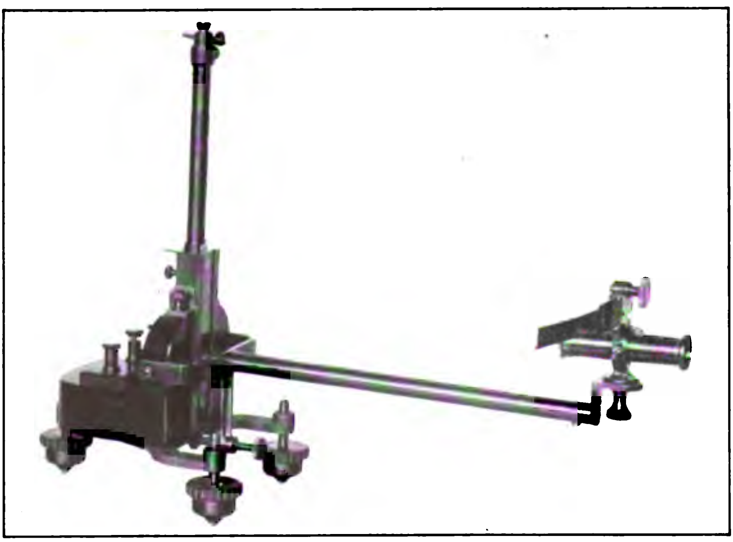


FIG. 134.—Mirror galvanometer.

south direction due to the influence of the earth's magnetic field, or to the field of artificial magnets mounted near it. Close to the center portion of the needle, generally surrounding it, is mounted a coil of insulated wire with its axis at right angles to the normal north and south direction of the needle. When the coil is energized from a source of electric current, the needle tends to move into a new position to a point somewhere between the original field and that of the axis of the coil, the distance through which the needle moves being dependent upon the strength of current in the circuit of which the coil winding forms a part.

The d'Arsonval type of instrument is the one generally used for commercial measurements.

So far as the principles involved, and operation are concerned, the galvanometer and the ammeter are identical. The former, however, may be used for detecting currents of a much lower value.

Figure 133 shows a make of portable d'Arsonval galvanometer used in connection with Wheatstone-bridge measurements.

Where exact measurements are necessary, a galvanometer of high sensibility, such as that illustrated in Fig. 134, is used. This form of d'Arsonval galvanometer has the moving element mounted between magnet poles and suspended from a point near the top of an upright tube by means of a very fine plated phosphor-bronze, silver, or steel wire. A small round mirror is fastened to the moving element, reflecting outward. The deflections of the coil, resulting from the presence of electric current in the winding, are measured by means of a telescope and suitable scale. The image of the scale in the mirror may be read through the telescope, or as variously used, the movement of a spot of light on a stationary scale mounted a short distance away from the mirror may be directly observed while measurements are being made. Due to the fact that the moving coil and its suspension are non-magnetic, and that the magnetic field in which the moving element turns is very strong, the readings of this current indicator are not appreciably affected by the earth's field, or other neighboring magnetic disturbances.

Differential Galvanometers.—For comparing the relative strengths of two currents, a galvanometer is sometimes employed in which the coil consists of two separate identical windings, mounted side by side. If equal currents are at the same time sent through both windings, there will be no deflection of the indicating needle, but should the currents be unequal in strength the needle is deflected, due to the influence of the stronger current; to a degree corresponding to the difference in the two current strengths. When the current strengths are equal, the effect of one coil upon the needle is completely neutralized by that of the other.

The Ballistic Galvanometer.—Ballistic galvanometers are employed to measure currents of momentary duration, such, for instance, as flow in a circuit when a condenser is discharged through it. With this instrument

the oscillation period of the needle must be long as compared with the duration of each discharge. As the needle which is long or heavy swings slowly around, the amount of deflection is additive, that is, the intermittent individual impulses impressed on the circuit result in a cumulative effect upon the needle. Where no damping of the needle is resorted to, the sine of half the angle of the first swing is proportional to the quantity of electricity that has flowed through the coil.

Galvanometer Shunts.—In cases where it is necessary or desirable to use a high sensibility galvanometer in making measurements requiring a considerably lower sensibility, the galvanometer coil may be shunted by a resistance having a definite ratio to that of the galvanometer coil. A formula for determining shunt values was given on page 86 in connection with Fig. 65.

Where galvanometers are not equipped with regular shunt-coils any ordinary resistance coil or coils of the correct value may be used for the purpose. As usually furnished with galvanometers, shunts are adjustable to 1/9, 1/99, or 1/999 of the galvanometer resistance, so that 1/10, 1/100, or 1/1000 part of the current only passes through the galvanometer coil.

Constant of a Galvanometer.—The constant or sensibility of a galvanometer refers to the value of the resistance in ohms through which 1 volt will produce a deflection of one degree on a standard scale, or to apply a general rule:

Multiply the deflection by the multiplying power of the shunt and by the resistance in the standard resistance box expressed in megohms or fractions thereof.

In Fig. 135 the necessary connections are shown for taking the constant of a galvanometer.

R, is a standard resistance of 100,000 ohms.

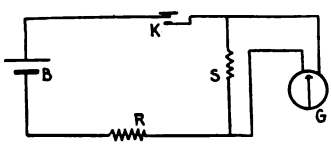


FIG. 135.—Taking the constant of a galvanometer.

Closing the key K will cause the galvanometer to be deflected d degrees. If then the shunt employed has a multiplying power of 1,000, obviously had no shunt been used the amount of deflection of the needle would have been 1,000 times as great. This at least would have been the case theoretically. Had a resistance of 1,000,000 ohms been used in place of 100,000, the deflection would have been but one-tenth of d; so that the deflection K, through 1,000,000 ohms in series with the galvanometer coil with no shunt applied would have been

$$K = \frac{1{,}000d}{10}$$

Where the multiplying power of the shunt is represented by m, the deflection

in degrees by d, and the resistance in megohms, or fractions thereof by R, then

$$K = Rmd.$$

The terms "constant," "figure of merit," and "sensibility," when used with reference to galvanometers, have the same meaning.

MEASURING THE RESISTANCE OF GALVANOMETERS

Half-deflection Method.—Connect the galvanometer as shown in Fig. 136. The resistance R and the source of e.m.f. B should be so regulated that the deflection of the galvanometer needle is over one-half of the scale. Note the deflection, then increase the resistance R until the needle moves

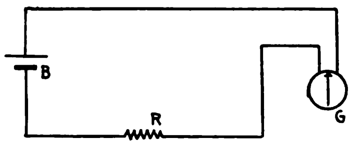


FIG. 136.—Half-deflection method of measuring the resistance of a galvanometer.

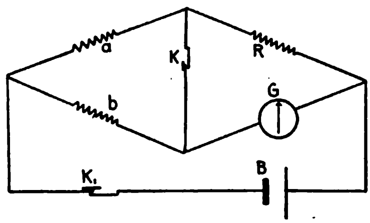


FIG. 137.—Kelvin's method of measuring the resistance of a galvanometer

to a point on the scale exactly midway between zero and the point of first deflection.

Disregarding the battery resistance, the resistance of the galvanometer will be the resistance of R measured at "half deflection," less twice the original resistance of R, or

$$G = r - R2.$$

Kelvin's Method.—Connect the galvanometer in the X arm of a Wheatstone bridge as shown in Fig. 137 and adjust R until the deflection of the needle is the same whether key K is closed or open, then

$$G = R\frac{b}{a}$$

Of course, where two galvanometers are available, the instrument whose resistance is desired may be inserted in the X arm, and the "bridge" balanced in the usual manner by means of the other galvanometer.

THE VOLTMETER

Measuring instruments which indicate the value of the e.m.f. in volts impressed upon their terminals are called voltmeters.

When a voltmeter is connected across the terminals of a source of e.m.f. a

current will flow through it which is directly proportional to the impressed voltage. Attached to the moving element (which in principle is the same as that of the d'Arsonval galvanometer) there is a light pointer moving across a scale which has been empirically graduated into divisions to indicate the value of the impressed e.m.f. Contained within the voltmeter casing there is a non-inductive resistance ranging in ohms from 10 to 2,000 times the full scale reading in volts. This resistance is in series with the winding of the movement coil, and it is customary to insert 100 ohms or more for each volt as indicated on the scale. The higher the series resistance per volt, the greater will be the accuracy of the indications.

There are various types of voltmeter available for different needs, among which might be mentioned the alternating-current voltmeter for measuring currents of a given frequency, one make of which has a mass of soft iron so placed that it will be moved into a solenoid, or from the center of a solenoid to one end, the movement of the soft iron plunger controlling the travel of a scale pointer. Also there are voltmeters based upon the principle of the electrodynamometer which may be used for either direct-currents or alternating-currents, and which are independent of variations in current frequency and of wave form.

Hot Wire Meters.—Hot-wire voltmeters and ammeters are used in which the passage of current through a length of thin wire causes a rise of temperature with consequent expansion of the metal conductor. As the wire expands, the slack is taken up by a spring, the resulting movement of which causes a pointer to travel across a properly graduated scale, thus indicating the strength of the current traversing the hot wire.

MULTIPLIERS FOR VOLTMETERS

The range of a given voltmeter may be increased by employing a suitable multiplier in the form of an additional external resistance placed in series with the voltmeter. With a low-reading voltmeter and a set of multipliers it is practicable to measure voltages covering a large range of values. Assume, for instance, that the only meter available is a 50-volt instrument, having 5,000 ohms resistance, and that it is desired to use the meter for measuring higher voltages. A multiplier with a value of 2 would measure 10,000 ohms, which would give a scale value for the meter of 100 volts. A multiplier with a value of 10 used with the 50-volt meter would measure 50,000 ohms, which would give the meter a scale value of 500 volts. It is, of course, understood that 50,000 ohms would represent the total resistance of meter and multiplier in series.

A formula applicable to any requirement might be stated thus:

$$R' = R\left(\frac{V' - V}{V}\right)$$

where R is the resistance of the voltmeter, R' the multiplier resistance to be connected in series with the meter, V the highest reading of the meter normally, and V' the highest reading desired.

The scale reading observed must be multiplied by $\frac{V'}{V}$ to obtain the correct value of the e.m.f.

CURRENT METERS

The ammeter and the milliammeter are instruments for measuring the current strength in circuits, the indicating scales being marked off into divisions representing amperes and milliamperes respectively. In the series ammeter the entire current to be measured traverses the coil winding of the instrument, and as in the case of the galvanometer, variations in the current strength cause the indicating needle to be deflected to a greater or less degree from its position of rest, the amount of deflection being dependent upon the value of the current in the circuit. For currents of any considerable volume, the shunt ammeter is generally employed in which a small portion only of the current is carried by the instrument coil. In portable ammeters the shunt coil is mounted in the base of the instrument.

BATTERIES FOR TESTING PURPOSES

Where line tests are made from terminal or intermediate test offices, generally there is available current from motor-generators or gravity batteries which may be applied in any desired manner, but where measurements are to be made from manholes giving access to underground cables, from aerial cable boxes, or from any point where regular battery is not available, it is necessary to employ a portable battery for the purpose.

Modern Wheatstone bridge sets have a self-contained dry battery source of e.m.f. which yields a current of sufficient strength for making all ordinary "bridge" measurements. They are also equipped with a conveniently mounted battery switch which makes possible regular main-line switchboard battery connections when the bridge is used for line testing from a terminal office.

Where the resistances involved are not great, ordinarily, dry cells serve the purpose satisfactorily, but in cases where high resistances are to be dealt with in making certain tests, potentials of at least 50 or 100 volts are best suited to the purpose.

Formerly the chloride of silver battery was extensively used for testing purposes. This form of battery met the requirements admirably, and has only recently given way to the more efficient storage battery, which is now available in light and compact units.

One excellent make of portable storage battery designed for testing purposes is known as the "Witham," or Marcuson battery. Several small storage cells are assembled in boxes to form batteries having certain ranges of voltage. There are four standard sizes, having maximum voltages as follows: 100 volts, 140 volts, 168 volts, and 256 volts. The boxes containing the battery complete weigh 17 1/2, 24 1/2, 29, and 42 lb. respectively. These batteries are divided into two or more sections, which by means of a commutating switch may be connected in series or in parallel, thus giving at the terminals either the full voltage of the battery or a fraction of same.

THE WHEATSTONE BRIDGE

This instrument consists of an arrangement of conductors as shown theoretically in Fig. 138. One terminal of the battery is led to the point *d*, where it divides into two paths which are united again at the point *c*, so that a portion of the total current flowing passes through the point *e*, and a portion through the point *f*. The four conductors *a*, *b*, *R*, and *X* are called the "arms" of the bridge. When the electrical resistances of three of the arms are known, the resistance of the fourth may be calculated according to the proportions of their relative values.

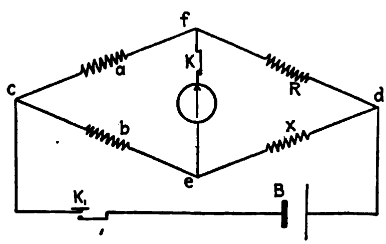


FIG. 138.—Theoretical connections of the wheatstone bridge.

What was said on page 87 in regard to "fall of potential along a conductor" (Fig. 66) has a direct bearing upon the underlying principle of the Wheatstone bridge.

Referring to Fig. 138: It is obvious that there will be a fall of electric potential between the battery terminal and the point *d;* also that there is a further drop along the upper branch *d, f, c*, and that the potential of the lower branch falls along the path *d, e, c.* If the point *e* and the point *f* are equally distant, electrically, from the point *d*, and in the same sense equally distant from the point *c*, then the potential will have fallen at *e* to the same value it has fallen to at the point *f*, or if the ratio of the resistance *a* to the resistance *R* be equal to the existing ratio between *b* and *X*, then the points *e* and *f* will have equal potentials. Connecting a galvanometer between the points *e* and *f*, as shown, furnishes a means whereby it is possible to observe whether or not the points *e* and *f* are at equal potentials. When such is the case, there will be no deflection of the galvanometer needle, or when the resistances of the four arms are in "balance" we have by proportion

$$a:b::R:X,$$

and if we know the resistance values of *a*, *b*, and *R*, *X* may be determined thus:

$$X=\frac{b}{a}R.$$

The unknown resistance or the resistance to be measured is inserted at X, that is, between the points d and e.

When the resistance to be measured is not greater than the total resistance of R, the ratio arms a and b may be made equal, then if the rheostat arm (R) of the bridge be adjusted until the galvanometer indicates a "balance," it is plain that the unknown resistance (X) has a value equal to that of R.

When it is desired to measure a resistance greater than the total value of R, the ratio arm b should be given a higher value than a, and to measure very low resistances the ratio arm b should be given a value less than that of a.

For example, let $\left.\begin{aligned} a&=10 \\ b&=1{,}000 \\ R&=540 \end{aligned}\right\}$ then $X=\frac{b}{a}=\frac{1{,}000}{10}\times 540=54{,}000.$

Let $\left.\begin{aligned} a&=1{,}000 \\ b&=10 \\ R&=540 \end{aligned}\right\}$ then $X=\frac{10}{1000}\times 540=5.4.$

COMMERCIAL WHEATSTONE BRIDGE INSTRUMENTS

There are several large instrument houses that manufacture high-grade measuring instruments and bridge sets, and when such apparatus is given proper care after being delivered by the manufacturer, generally it will be found to be quite constant and reliable in performance, and will have long life.

One of the newer makes of bridge is illustrated in Fig. 139. In this particular set the battery is inclosed within the casing and consists of four dry cells of a stock size. The rheostat, or R arm of the bridge system is composed of four dials of ten coils each, which have values of units, tens, hundreds and thousands ohm coils. The ratio arms a and b have values of 1, 10, 100 and 1,000 ohms in each arm. The galvanometer, which is of the d'Arsonval type, is mounted flush with the floor of the box containing the resistance coils. The scale has 30 millimeter divisions with center zero. A zero adjustment is provided which enables the tester to bring the needle exactly on zero, or on any point of the scale desired. Instead of metallic plugs being used to cut-in or cut-out the various resistance units, radial brush contacts are provided which swing in a complete circle in either direction, going from the highest value to the lowest value coil in any decade, without having to be turned back over the intervening contacts.

By means of extra binding-posts and accessible switches it is possible to substitute an external source of e.m.f. in place of the dry-cell battery contained within the box, and to employ a separate galvanometer in place of the one mounted as a part of the set.

Included as a part of the equipment of the set is an Ayrton shunt which allows full current, 1/10 part, or 1/100 part of the current to

flow through the galvanometer of the set or external galvanometer, whichever is used with the bridge at the time.

The set described, in common with other modern Wheatstone bridge sets may be used in making the following tests:

FIG. 139.—Commercial form of wheatstone bridge, including galvanometer and self-contained dry-cell battery.

Measuring resistance by the bridge method.
Measuring insulation resistance by the direct deflection method.
Comparing e.m.f.'s by the fall of potential method.
Checking up voltmeters.
Measuring battery resistance.
Making the Murray loop test.
Checking up ammeters by using a shunt of known value.
Making the Varley loop test.
Testing out "grounds."
The galvanometer and battery can be used in series.

THE ELECTRIC CONDENSER

The fact that both long and short metallic conductors used in forming electrical circuits possess capacity, means that when the electrostatic capacity of a conductor is to be measured, or when the static discharge from line conductors is to be compensated for, it is sometimes necessary

to have available for these purposes electric condensers having variable capacities.

In considering the theory of the electric condenser, it might be stated that the factors involved are a source of electric charge, a conductor of electricity, and a dielectric (insulator).

One of the most comprehensive generalizations relating to electrostatics, established by Faraday, was that all electric charge and discharge is essentially the charge and discharge of a Leyden jar (a form of electric condenser).

The original form of condenser, the Leyden jar, owes its name to the city in which it was invented. The appearance of this condenser is illustrated in Fig. 140.

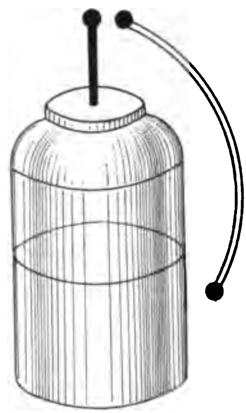


Fig. 140.—Original form of Leyden-jar condenser.

Later forms of the Leyden jar were made with an inside and an outside coating of tin-foil reaching from the bottom to within 2 or 3 in. of the top of the glass jar. A shellaced wooden top fitted into the neck of the jar, served as a support for a brass knob mounted on the upper end of a brass wire; the latter extending through a hole in the top had affixed to its lower or inside end a length of brass chain reaching to the bottom of the jar and in contact with the inside foil coating: the efficiency of the jar as a condenser being considerably increased by the application of a coating of shellac, due to the fact that shellac very materially retards the dissipation of the charge over the uncovered surfaces of the jar. Condensation of moisture on the surface of the glass interposes a conducting path, even if of very high resistance, which permits gradual equalization of the opposite charges gathered on the tin-foil surfaces attached to the inside and to the outside of the jar.

From this brief description it is evident that a Leyden jar condenser, like any other form of electric condenser, consists simply of two conductors separated by an insulator. The capacity of any form of condenser, that is, its ability to retain a greater or less quantity of charge, is dependent upon the area of the conducting surfaces and upon their distance apart.

COMMERCIAL, OR STANDARD CONDENSERS

The capacity of commercial condensers is either fixed or variable, or as more commonly stated, non-adjustable or adjustable, respectively.

A non-adjustable condenser has its conducting surfaces, or leaves, arranged as shown in Fig. 141, in which the leaves are represented by vertical lines and the connecting metal strips by horizontal lines.

Alternate leaves are connected with the metal strip *A*, while every other alternate leaf is connected with the metal strip *B*, as shown. Condensers constructed so that their capacity may be adjusted or varied, have alternate leaves connected with a common terminal as shown in Fig. 142, while the remaining alternate leaves are connected in groups which may be placed in contact with the other condenser terminal *B*, at 1, 2, 3, 4, etc., as desired, by inserting metallic plugs in contact plates distributed at these points.

It is important to note that an adjustable condenser when completely assembled and connected for full capacity, is simply a number of non-adjustable condenser units arranged in parallel.

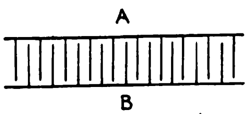


FIG. 141.

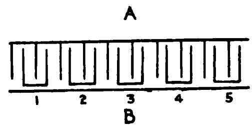


FIG. 142.

Capacity of Condensers.—The joint capacity of condensers connected in parallel is equal to the sum of their respective capacities, or in the case of two condensers

$$\text{Total capacity} = C_1 + C_2$$

The joint capacity of two condensers connected in series is equal to the product divided by the sum of their respective capacities, or

$$\text{Total capacity} = \frac{C_1 \times C_2}{C_1 + C_2}$$

Where three condensers are connected in series, the joint capacity

$$= \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Or for any number of condensers in series, the joint capacity is equal to the reciprocal of the sum of the reciprocals of their respective capacities, thus following the law of the joint resistance of parallel circuits as explained in a previous chapter. When combined in multiple series, the same law applies, the total capacity of each group of condensers connected in parallel being regarded as the capacity of a single condenser in order to obtain values for the purpose of computing the total capacity available from a given arrangement.

MEASURING CAPACITY

Occasionally it is necessary to determine the capacity of a condenser, a line wire, or cable conductor. One method of obtaining the desired in-

formation is that known as the direct deflection method, and the procedure is as follows: charge a standard condenser C_1 Fig. 143, from a source of e.m.f. for a period of, say, 30 seconds, then discharge the condenser through a galvanometer (preferably a ballistic, or an astatic galvanometer); note the deflection and call it d. Next charge the condenser to be measured from the same battery and for the same period of time, and discharge it through the galvanometer in the same manner. Note the deflection of the needle, and call this d_1

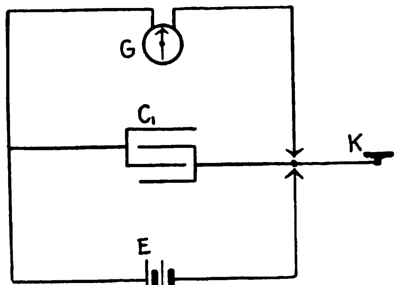


FIG. 143.—Measuring the capacity of a condenser by the direct-deflection method.

Then $\qquad C_1 : C :: d : d$

and

$$C = C_1 \frac{d_1}{d}.$$

Bridge Method.—Connect the two condensers to be compared as shown in Fig. 144. R_1 and R_2 are non-inductive resistances of about 2,000 ohms each, G a galvanometer, E a source of e.m.f., and K a key. Adjust the resistances R_1 and R_2 so that there is no deflection of the galvanometer needle when the key K is manipulated.

Then $$C = C_1 \frac{R_1}{R_2}$$

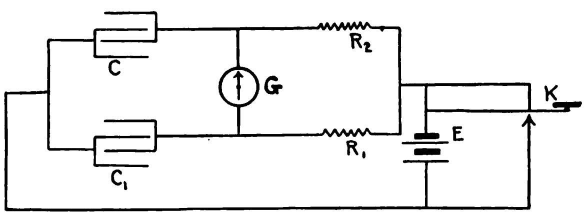


FIG. 144.—Comparing the capacity of condensers by the bridge method.

Modern commercial adjustable condensers are made up of a number of small units assembled within a sheet-iron or tin case, equipped with sliding contacts controlled by a revolving knob by means of which the capacity of the condenser is varied. The sliding contacts take the place of the peg-and-hole connections formerly used.

Insulation Resistance of Condensers.—It might be supposed that the insulation resistance between the two terminals of a condenser is infinitely high, but it is found that condensers, as usually manufactured, sometimes have an insulation resistance so low that when the condenser is inserted

between line and ground, the circuit through the condenser in reality forms a high-resistance leak. In telegraph practice, a condenser which is found to have an insulation resistance between terminals of not less than 500,000 ohms is regarded as satisfactory for all practical requirements.

Using a standard milammeter, with an applied e.m.f. of 375 volts, one division[1] deflection on the lower scale of the milammeter represents an insulation of 1.8 megohms. Therefore a condenser tested with 375 volts pressure which shows more than 3 1/2 divisions deflection on the lower scale of the milammeter has an insulation resistance too low for satisfactory service.

MEASURING THE INTERNAL RESISTANCE OF BATTERIES

The well-known half-deflection and direct-deflection methods of measuring the internal resistance of batteries, formerly extensively employed,

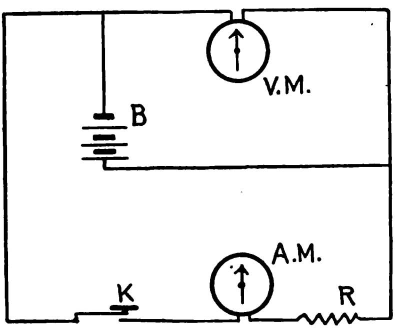


FIG. 145.—Measuring the internal resistance of a battery by the voltmeter-ammeter method.

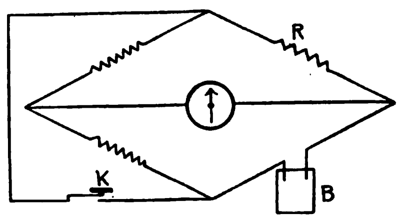


FIG. 146.—Measuring the internal resistance of a battery by the bridge method.

have been superseded in modern practice by the employment of the voltmeter-ammeter, and the bridge methods of making these measurements.

Voltmeter-ammeter Method.—In making this test the ammeter is connected through a resistance in series with the battery, the internal resistance of which is sought, while a high-resistance voltmeter is connected in shunt with the ammeter circuit as shown in Fig. 145.

With the key K open, the volmeter reading E is noted. Then with the key closed simultaneous readings may be taken of the voltmeter E_1 and the ammeter I, then the resistance of the battery

$$B = \frac{E - E_1}{I}.$$

Bridge Method.—The battery to be measured is connected in the X arm of the bridge as shown in Fig. 146. With a and b equal, adjust R until the galvanometer deflection with the key K open or closed is the same.

[1] Five divisions on the lower scale represent 1 milampere.

On account of the necessity for altering the regular bridge set connections when making this test, it is generally preferable to employ a portable galvanometer and separate resistance boxes.

EARTH CURRENTS

In those measurements where the ground is used as a portion of the completed circuit, occasionally earth currents introduce errors which make the readings unreliable. Also it is of considerable importance in certain operations to determine the value of the difference of potential between terminal offices due to earth currents. In the case of grounded-circuit measurements, where the earth current is fairly constant in potential and polarity, its effect may be compensated for by making first a measurement with the negative pole of the home battery to line, and then with the positive pole to line. If the readings have an appreciable difference in value, their average should be taken as the correct result.

Measuring Earth Potentials.—There are several methods of determining the potential of the earth between two points, but for practical requirements the simplest way, and which requires no calculation, is to use a voltmeter for the purpose. If the meter has a double scale, use the one giving the greatest deflection with minimum potential difference.

To make the test, remove all regular battery from the line. Ground the line at both ends, that is, at each terminal of the wire under test. Connect the voltmeter into the line at the switchboard by means of a "wedge" or otherwise. This will connect the voltmeter direct from line to ground. If when the meter circuit is closed while the binding-post marked (+) is to line, the indicating needle moves to the right, then the ground at the distant station is positive to the home ground. If the needle swings to the left, reverse the wedge so that the post marked (+) connects with the home-station ground in which case the ground at the distant station is negative to the home ground. In noting the readings, the polarity as well as maximum and minimum potential readings should be recorded.

MEASURING THE RESISTANCE OF EARTH CONNECTIONS

One method of ascertaining the value of the earth resistance between two stations which may be applied where two line wires are available between the stations, is shown in Figs. 147 and 148.

The two line wires are "looped" together at the distant station, and at the home station are connected in the X arm of the bridge, as illustrated in Fig. 147. The looped resistance is noted. Assume, for example, that it is found to be 6,000 ohms. Call this R_1. Then, as in Fig. 148, measure the resistance of one of the wires between the home station and the ground at the distant

station. In like manner measure the resistance of the other wire. Say that one was found to measure 3,204 ohms, and the other 2,812 ohms, or a total of 6,016 ohms. Call this value R_2. Then, resistance of the distant ground (assuming that the resistance of the home ground is nil)

$$G = \frac{R_2 - R_1}{2},$$

or $$6{,}016 - 6{,}000 \div 2 = 8. \quad \text{Ans. 8 ohms.}$$

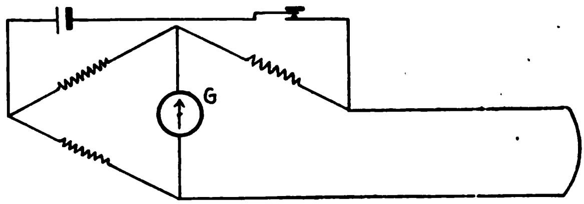


FIG. 147.

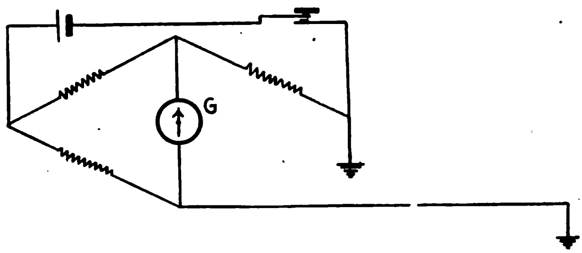


FIG. 148.

FIGS. 147 AND 148.—Measuring the resistance of earth contacts.

In view of the variable conductivity of contacts made through "peg" switchboards, where this method of grounding is employed, it is essential that positive contacts be made, otherwise errors will be introduced which produce misleading results. It is, however, an excellent and quick method of determining whether or not a suspected ground connection has a resistance abnormally high.

Another method, and one which takes into consideration the value of the voltage impressed on line wires due to earth potentials, is shown theoretically in Fig. 149.

In this test, the regular galvanometer of the bridge set is replaced with a voltmeter, all other connections remaining the same. The resistance of the line wire extending between the home station and the station where the ground resistance is to be determined is measured by means of the loop method, after which this wire is "grounded" at the distant station. The R arm of the bridge has all of its resistance plugged out, then with the arm

a or *b* opened temporarily the voltmeter indicates the value of the earth potential from the distant ground. In most cases this value will be found to fluctuate somewhat, and it will be necessary in such cases to note the mean deflection. The key should be left open while this reading is taken. Now close the key and with positive pole of battery to line raise the resistance of the *R* arm of the bridge until the deflection is of the same value as that first observed. Call this reading *A*. Reverse the battery terminals so that the negative pole will be to line. Close the key and adjust the resistance *R* until the voltmeter again shows the same value. Call this reading of *R*, *B*.

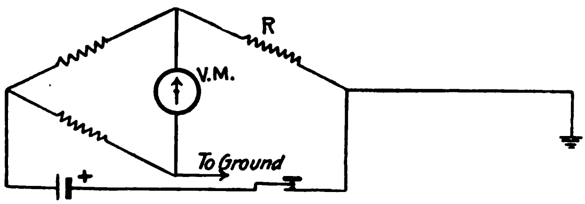


FIG. 149.—Measuring the resistance of earth contacts, where earth currents exist.

Then the resistance of the line wire plus that of the ground connections at each end will be

$$\frac{A \times B}{A + B} 2.$$

If the line resistance as at first calculated is now deducted from the result obtained, the remaining figure will represent the resistance of the distant ground connection. Assuming, of course, that the resistance of the home ground connection is known to be nil.

MISCELLANEOUS TESTS

In what follows, various methods of testing "opens," "grounds," "crosses," "escapes," "insulation," "conductivity," "resistance," "capacity," etc., will be explained. It might be deemed sufficient to give one approved method of making each measurement or test, but as it is not likely that the testing equipment of a given telegraph administration, or of a given railroad telegraph system is the same at all of its testing offices, it has been thought best to submit alternative methods covering each test, so that no matter what the conditions are the attendant may have at hand a method of making the desired test which will meet the requirements.

It is well, too, for the younger wire chiefs to seek an understanding of the various standard methods of making all necessary measurements, for, by virtue of possessing such knowledge they are better able to grasp the principles involved and to understand the subject generally.

WHEATSTONE BRIDGE MEASUREMENTS

Where strap-and-disk main-line switchboards are employed, the practice of the Postal Telegraph-Cable Company provides permanent connections between the testing set and disks in the main-line board, as shown in Fig. 150.

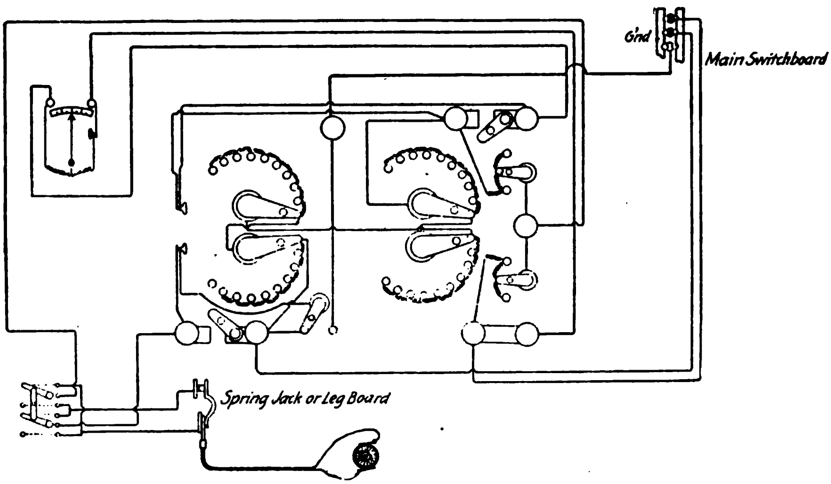


FIG. 150.—Wheatstone bridge permanently connected to main line switchboard.

It may be seen that the line binding-posts (the *X* arm) of the bridge are connected to separate disks in the switchboard, and that a third wire is brought to another disk in the switchboard for the purpose of grounding one side of the bridge when so required in making certain tests. The electrical connections of the bridge shown are identical with those shown in the theoretical bridge diagram, Fig. 138, with the exception that short-circuiting switches are provided for the purpose of permanently closing the galvanometer and battery keys. Also, a battery reversing switch and a grounding switch are added for convenience in making required tests. Theoretically the connections would be as shown in Fig. 151.

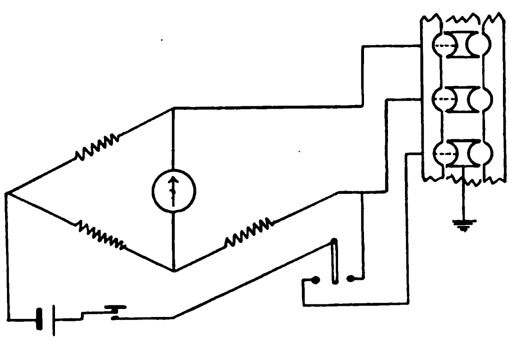


FIG. 151.—Theoretical circuits of bridge connected to main line switchboard.

Practically all of the troubles to which telegraph lines are subject may be investigated with the bridge circuits arranged as shown in Fig. 152.

In those cases where the resistance of a "cross" varies within wide limits, and a third wire is taken for the purpose of making the desired measurement, the battery is "grounded" as shown in Fig. 153, the other bridge connections remaining the same.

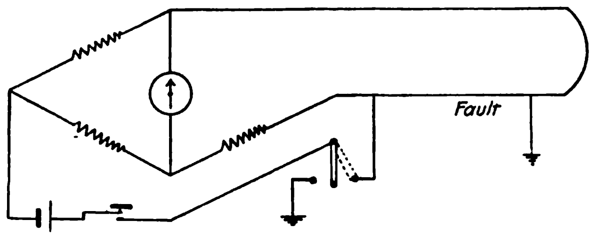


FIG. 152.—Arrangement of bridge connections for locating faults in telegraph circuits.

Wheatstone bridge measurements are divided into two general classes, usually spoken of as the "Murray" and the "Varley" methods. In making certain tests, the Murray method offers an excellent means of obtaining quick results. In other cases this method of testing is not as applicable, owing to

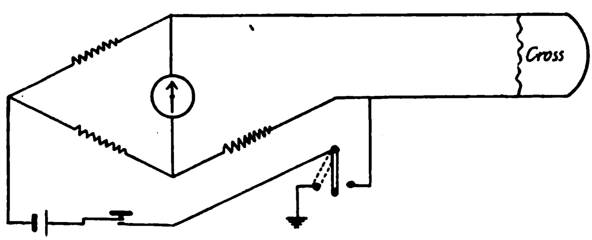


FIG. 153.

the requirement that the conductors under test must be of the same size and length, and of the same material. The Varley method is, generally speaking, more applicable to everyday telegraph requirements than is the Murray method.

THE MURRAY LOOP TEST

Referring to Fig. 154. Where it is desired to locate grounds or crosses in open lines or in cables, when the Murray method is employed it is not necessary that the ohmic resistance of the conductors under test be known, so long as both wires comprising the loop formed are of the same length, size, and kind.

For the purposes of telegraph line testing, generally 1,000 ohms is the

best resistance to have cut-in in the *a* arm of the bridge. As shown in Fig. 154, the arm *b* is short circuited; the adjustable resistance (arm *R*) now in effect taking the place of the arm *b*. The testing battery is connected to the dividing point *D*, through the key *BK*; the galvanometer and its key *GK*, to the bridge terminals *GW* and *FW*.

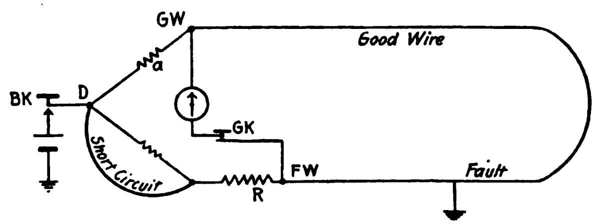


FIG. 154.—Bridge circuits arranged for locating a "ground" by the Murray loop test.

TO LOCATE A GROUND

Loop the faulty wire with a good conductor of the same gage and length at the distant station. Connect the good wire to the terminal *GW*, and the faulty wire to the terminal *FW*. Obtain a "balance" by closing both battery and galvanometer keys for a moment, repeatedly. At the same time adjust the resistance of the rheostat until there is no response of the galvanometer needle to the manipulation of the keys. Then, the distance to the fault may be determined by applying the following formula:

$$X = \frac{R \times L}{B + R}$$

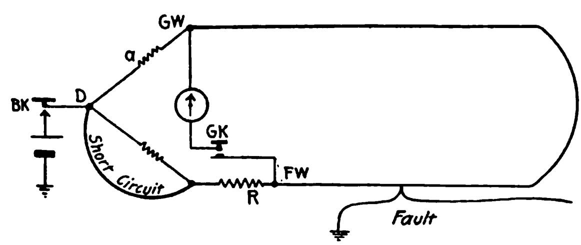


FIG. 155.—Bridge circuits arranged for locating a "cross" by the Murray loop test.

Where X represents "distance" to fault.
B represents resistance in *a* arm of bridge.
R represents resistance in rheostat after balancing.
L represents length of loop in feet or miles.

To illustrate: Suppose the conductor under test is 3,700 ft. in length, then the

length of the loop formed by two similar lengths would be 7,400 ft. If when a balance has been obtained it is found that the unplugged resistance in the rheostat is 42 ohms, and 1,000 ohms resistance in arm *a*, then the distance from the testing station to the fault is:

$$\frac{7400\times 42}{1000+42}=\frac{310800}{1042}=298.3 \text{ ft.}$$

CROSSES

Should the fault be a cross instead of a ground, ground one of the crossed wires as shown in Fig. 155.

CORRECTION FOR LEAD-WIRE RESISTANCE

It is well to avoid the employment of connecting wires between the bridge and the conductors under test. When necessary to do so, use wires of the same gage, or of the same aggregate dimension as the conductors, and add the combined length of the connecting wires to the length of the loop formed by the conductors proper. After obtaining the result by the formula given, deduct the length of the short wire connected to the faulty conductor, and the remainder will be the distance to the fault. For instance, if in the previous example, it were necessary to use connecting wires 10 ft. in length, the formula would resolve into:

$$\frac{(7400+10+10)\times 42}{1000+42}\ \frac{7420\times 42}{1042}\ \frac{311640}{1042}=299.$$

299–10 (length of one connecting wire) = 289 ft., distance to fault.

VARLEY LOOP METHOD

In those instances where faults are to be located on loops formed of conductors having sections of different dimensions, the Varley method may be used to good advantage.

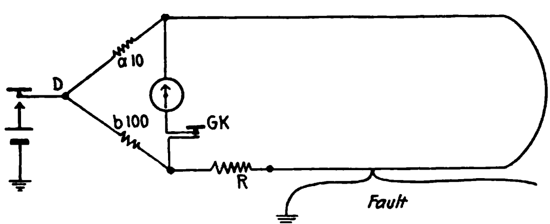


FIG. 156.—Bridge circuits arranged for the Varley loop test.

In Fig. 156 the faulty wire is looped with a good conductor at the distant station, after which the resistance of the loop thus formed is measured by the regular Wheatstone bridge method. When the resistance of the loop has been determined, the connections for the Varley test are made as shown in Fig. 156.

In practice the best results are obtained when the arm a has 10 ohms resistance, and the arm b 100 ohms. Obtain a balance by closing both keys repeatedly while the resistance of the rheostat is adjusted until the galvanometer needle is not deflected. The resistance to the fault is determined by means of the formula:

$$x=\frac{(R_1+R)b}{a+b}-R.$$

Where x represents resistance to fault.
R_1 represents resistance of loop.
R represents resistance in rheostat.
a represents resistance in arm a.
b represents resistance in arm b.

To illustrate: If the loop has a resistance of 420 ohms and a balance is indicated when the rheostat has a resistance of 2,560 ohms, with a 10 ohms, and b 100 ohms, then the resistance to the fault will be:

$$\frac{(420+2560)\times 100}{10+100}-2{,}560=\frac{298000}{110}-2{,}560=2{,}709-2{,}560=149.$$

If the faulty wire is a No. 10 B. & S., gage copper conductor, it may be ascertained by referring to the table of wire gages (see tables in appendix) that its resistance is 5.28 ohms per mile at 60° F., which for all practical purposes is sufficiently accurate at all ordinary temperatures. If then the resistance to the fault (149 ohms) be divided by the resistance per mile, of the wire (5.28 ohms), the quotient 28.2 miles will be the distance to the fault. If short wires are used between the bridge and the conductors tested, ascertain the resistance of the short wire connected to the faulty wire and deduct its resistance from the total resistance to the fault.

For example: had connecting wires been used in the above instance, and that connected to the faulty wire found to measure 2 ohms the end of the formula would be $149-2=147$ ohms actual resistance to the fault. And $\frac{147}{5.28}=27.8$ miles to fault.

Obviously, any measurement made in the above described manner, may be checked for accuracy by reversing the individual "legs" of the loop in the bridge, and computing the resistance of, or the distance to the fault along the good wire and back along the faulty wire.

In those instances where there are indications of current in the crossed wire due to foreign battery, which cannot conveniently be eliminated, remove the regular battery from the testing set and substitute a ground connection in its place.

In making Wheatstone bridge measurements, the battery key should be closed a moment or so in advance of the closing of the galvanometer key;

this to avoid momentary false indications of the needle. Also, care should be taken to have current in the bridge coils during the shortest possible time, in order to avoid charring of the silk insulation of the wire.

TO MEASURE THE CONDUCTOR RESISTANCE OF GROUND RETURN CIRCUITS

Arrange the bridge connections as shown in Fig. 148. Adjust the bridge arms, and balance as previously explained. To accurately measure the resistance of a wire, where two other wires between the same points are available, proceed as follows:

Suppose it is desired to measure the resistance of the wire *X*, Fig. 157.[1] Measure separately the resistance of loops made up as follows:

Wire *X* with wire *Y*,
Wire *X* with wire *Z*,
Wire *Y* with wire *Z*,

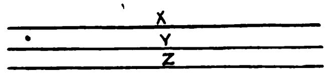


FIG. 157.

If the first loop measures 90 ohms, the second 93 ohms, and the third loop 99 ohms, then the total resistance of the three loops is 282 ohms. As each of the wires was used twice in making up the loops measured, the total resistance of the three wires measured once, obviously would be one-half of 282, or 141 ohms; and as the resistance of the loop formed of the two wires *Y* and *Z* is known to be 99 ohms, the resistance of the wire *X* is obtained by deducting 99 from 141, leaving 42 ohms as the resistance of *X*. Once the resistance of one wire is known, the resistance of each of the other wires is determined by looping the wire of known resistance with the wire to be measured and then subtracting the resistance of the first wire measured from the resistance of the loop.

METHOD OF LOCATING "OPENS" IN CABLES

An excellent test in cases where the insulation is normal, may be carried out by connecting the bridge as shown in Fig. 158. *G* is a source of alternating current. Where current from an alternating-current dynamo is not available, a small induction coil may be used to supply the desired current. Another convenient method of providing an alternating-current source, is to connect two double-contact relays, or transmitters, as indicated in Fig. 159, where a source of direct current is shown connected in series with a vibrating bell and the windings of two transmitters. A second source of direct current is connected with the local contact points of the transmitters in the manner illustrated. As the circuit through the coils of the transmitters is continuously opened and closed, due to the operation of the vibrating bell, it is evident that the current sent out on the lines connected to the respective armatures of the transmitters, will be alternating in character.

[1] "Examples from Postal Telegraph-Cable Co.'s book of instructions."

For cables approximately 1,000 feet in length, the alternating-current generator should have an e.m.f. of from 40 to 130 volts, and the arm *a* of the bridge may have a resistance of 100, or 1,000 ohms. The capacity of a conductor increases as its length is increased: the greater the capacity of the conductor under test, the lower should be the voltage of the testing battery, and the lower should be the resistance of arm *a* of the bridge.

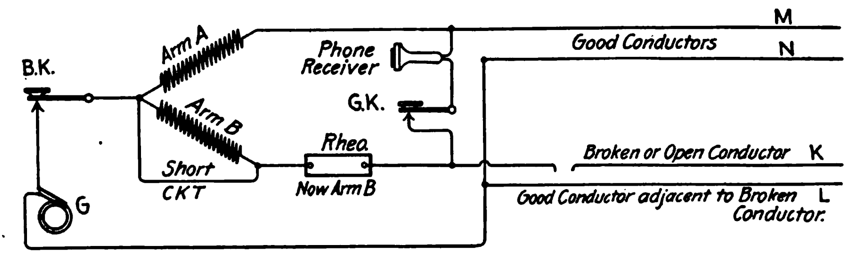


FIG. 158.—Method of locating "opens" in cabled conductors.

To locate a break in a cable conductor, pick out three good conductors having the same gage as the open wire and connect them as shown in Fig. 158. The conductors selected should have relations as shown in Fig. 158, that is, L must be adjacent to K, and N adjacent to M. To obtain a balance, open the four wires under test at the distant end, close keys GK and BK and adjust the resistance in the R arm of the bridge until no sound, or at least until minimum sound is heard in the telephone receiver when placed to the ear.

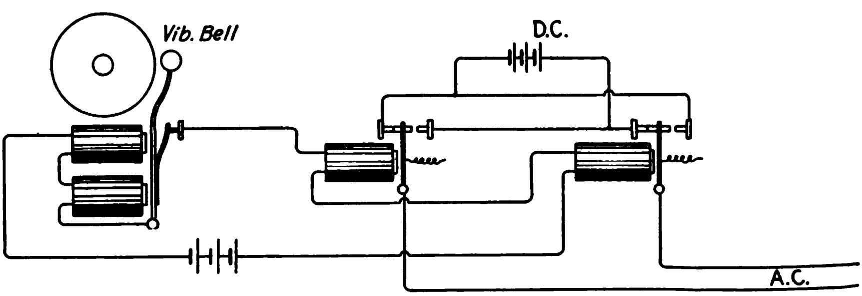


FIG. 159.—Convenient arrangement for supplying an alternating current for testing purposes where an alternating current dynamo is not available.

Then the distance to the fault

$$X = \frac{L \times a}{R}$$

Where X represents the distance in feet, to fault,
L represents the length of the cable in feet,
a represents resistance in arm a,
R represents resistance in arm R.

For example: Suppose we have a cable 5,280 ft. in length, and that a balance of the bridge is obtained when the unplugged resistance in the R arm is 1,872 ohms, while a has a resistance of 100 ohms. Then the distance from the testing station to the fault is:

$$\frac{5280 \times 100}{1872} = 282 \text{ ft.}$$

THE BLAVIER TEST

A method known as the Blavier, sometimes used for locating a partial ground or an escape, where there is no good wire available for looping purposes, may be carried out as follows:

Let r_2 represent the total resistance of the conductor under test (this must be known from previous measurement, obtained from a wire table, or calculated from the length, size and conductivity of the wire). Let R represent the resistance of the wire with the distant end open, and r_1 the resistance of the wire with distant end grounded. Then, the resistance from the testing point to the fault

$$x = r_1 - \sqrt{(R - r_1)\ (r_2 - r_1)}$$

By dividing x by the resistance per unit length of the conductor, obtained as above suggested, the distance to the fault is arrived at. If L represents the length of the conductor in feet, and r_2 the normal resistance of the faulty wire to the distant end of the line, the distance in feet to the fault

$$= \frac{xL}{r_2}$$

The accuracy of measurements made by this method depends upon the resistance of the fault remaining constant during each measurement.

There are instances where the resistance of the fault is so high or so variable that the Blavier method is not reliable, and in general it is found that the Murray arrangement (Fig. 158) is more satisfactory, where additional good conductors are available for the test.

THE FISHER LOOP TEST

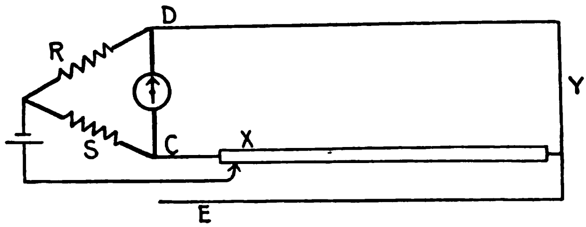
This test may be used in cases where there are two good conductors available which terminate at the same point as the faulty wire. It is not necessary that the resistances of the conductors be equal, so the good wires used for the test may be in another cable, or may be open aerial wires.

In Fig. 159*a* the faulty wire C and the good wires D and E are shown connected at the distant station Y. It is then necessary to make two separate tests. First, one side of the battery is connected to the sheath as shown at

X. The resistance S is adjusted until the galvanometer needle shows no deflection. The resistance values of R and S are noted. Then as in 159*b* the battery is connected to the good conductor E, and a balance taken, the resistance values being noted as R_1 and S_1. Then if L equals the length of the faulty wire, the distance to the fault is determined by the formula

$$D=\frac{S(S_1+R_1)}{S_1(S+R)}\times L.$$

In cases where connecting wires are used between the testing set and the actual conductor connections, the connecting wire entering into the measure-



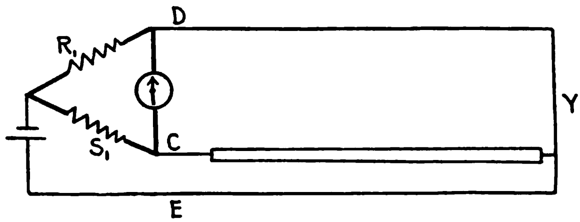


FIG. 159.—Fisher loop test.

ment is the one extending from the bridge to the faulty wire. In the Fisher tests, the same rules apply in locating crosses and shorts as in the Murray tests.

ROUGH TESTS

When a wire chief has become thoroughly familiar with the electrical and physical characteristics of the various line conductors in his division he is in a position to apply certain rough tests, which although they do not produce accurate figures, often serve to restore circuits quickly, especially where trunk-line facilities are limited.

In switch-board parlance, each main-line circuit has its "feel," and a wire chief familiar with the peculiarities of a particular circuit, can

tell by "feeling" it whether conditions are normal or abnormal. Consider, for instance, a line wire extending between two terminal stations 200 miles apart, and that there are 10 intermediate offices connected into the circuit, each intermediate office having inserted in the line a relay of 150 ohms resistance. If the circuit is opened at the distant terminal (by opening the line key or disconnecting the ground wire) then, provided battery is applied to the line at the home station, when the home key is closed at intervals, as in making "dots" slowly, there will be a pronounced "static" kick as current momentarily traverses the coils of the home relay, causing the relay armature to be attracted to an extent directly dependent upon the capacity of the line wire, and upon the number of relays included in the circuit. As the circuit is open it is evident that the effect on the home relay is due to the capacity of the line wire, which means that the longer the line and the greater the number of relays in circuit, the greater will be the force producing the kick of the home relay armature. Therefore when a ground return circuit opens at an unknown point, if the "kick" of the relay armature has about the same strength, or "feel" as when the line key at the distant terminal is opened, it is likely that the line is open at a point near the distant terminal. If, however, the kick is feeble, the line is open near the home station. And generally the strength of kick indicates to the tester the approximate distance to the fault, enabling him to call in an intermediate office near the fault on another wire. Thus, time is saved which otherwise would be consumed in tracing the fault from station to station along the line from the terminal office.

Had the trouble which developed on the line been the result of an accidental ground contact instead of an "open," the wire chief's knowledge of the normal operating characteristics of the circuit enables him to apply a rough test to determine the approximate location of the ground. Under normal conditions a circuit has a regular e.m.f. applied to it. This, with the regular resistance of line plus relay resistance, permits of a definite current value in the circuit. Normal operating current produces what might be called "normal pull" on the armature of the relay. In the case under consideration, where the line wire is supposed to be "grounded" at an unknown point between the two terminals of the line, if it is found that the magnetic "pull" of the testing relay is abnormally strong, it is evident that the wire is grounded at a point not far distant from the home station. If on the other hand the pull is about normal, the ground in all probability will be found not far from the distant terminal of the line. And, in general, the strength of the current flowing through the home relay indicates to the tester approximately the distance to the accidental ground contact.

When two wires entering the same switchboard become "crossed" somewhere out on the line, it is not always immediately apparent which two are in contact. When a wire shows a cross with another circuit carrying current, the identity of the latter may be ascertained by removing the regular battery

from the first wire, and grounding that circuit at the home station through a test relay at the switchboard. The relay thus inserted in the line has its winding energized by a current which enters the wire at the "cross," and the procedure of the rough test is to open consecutively each wire which follows the same pole route, until one is found which when opened (thus removing its battery) opens also the wire in which the test relay is inserted. The point at which the cross exists may be located by having intermediate stations with this wire cut into their switchboards, open the circuit for a few seconds. If the test progresses from station to station away from the home station, the first station called in, whose open key fails to open the test relay, is, in fact, the first station beyond the cross, and the point at which the fault exists has been located between two certain stations.

The above method of identifying crossed wires is applicable only where the wires involved take main battery at the testing station only, or in cases where main battery supplied at the distant terminal is temporarily removed from the wires affected. When two wires are crossed, and until the cross is cleared by a lineman detailed for that purpose, one good circuit may be made up by having a station on each side of the cross (in each case as close to the cross as possible) open the least important circuit. This creates a condition such as that shown in Fig. 160, permitting one good circuit to be restored to service between the terminals of the line.

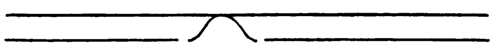


FIG. 160.

ALL CIRCUITS INTERRUPTED

It occasionally happens, due to storms, sleet, fire or other cause, that all wires on a route are at a certain point grounded, crossed, or open. Such a condition is usually referred to as a wreck. When this happens, the wire chief having jurisdiction over this particular section, is called upon to make good as many circuits as possible and as quickly as he can. In the language of the "board" he is required to "dig a hole through."

The arrangement shown in Fig. 161 furnishes a means for obtaining quick results in case of a general wreck of wires.

It may be seen that one side of the testing relay is grounded. The test requires that the other side of the relay circuit be connected in turn with each of the line conductors involved. While the relay is connected in series with a particular wire, all other wires are opened at the home switchboard, and battery applied to the wire under test. The closing of the relay armature tongue indicates a cross between the wire connected through the relay and the wire to which the battery is applied. With this arrangement it is possible quickly to ascertain which wires are crossed, which open, which grounded, etc.

After repairmen arrive at the wreck, and the restoration of circuits begins, it is of considerable advantage to employ an automatic arrangement at the testing office, which will announce to the wire chief when a fault has been cleared. The arrangement illustrated in Fig. 162 is extensively employed for this purpose.

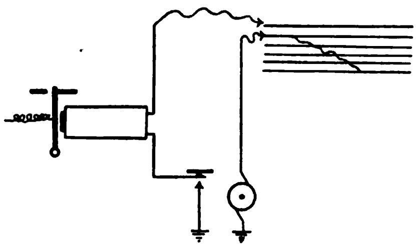


FIG. 161.

Suppose, for instance, that the wire shown connected to the relay through the main switchboard and spring-jack is grounded through a battery. Switches S and S_1 are thrown to the left, thus placing the vibrating bell in circuit through the back contacts of relay R. The office first beyond G (the ground contact) is instructed to leave the grounded wire open. As long as the circuit remains grounded at the point G the relay R is energized and its armature remains in the closed position, which leaves the bell circuit open. As soon, however, as the ground at G is lifted, relay R opens, due to the fact that the circuit is open at the station first beyond G, and immediately the signal bell announces the removal of the ground contact.

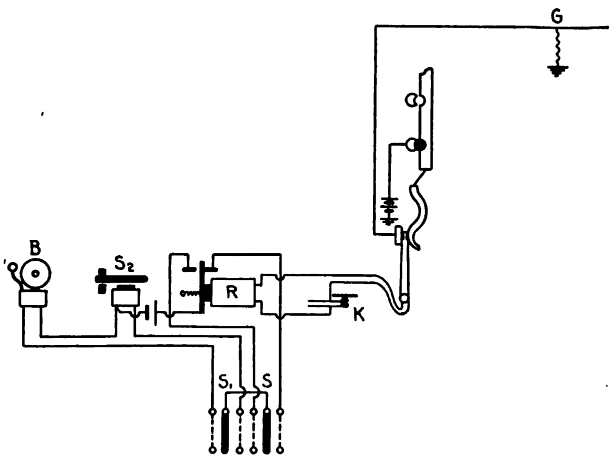


FIG. 162.—Wire chief's test relay and signaling bell connected to announce the removal of a ground contact or the closing of a break.

Switches S and S_1 are then thrown to the right, which places the regular sounder in circuit in place of the signal bell. Had the wire under observation been open tinsead of grounded, the distant terminal station would have been instructed to keep his end of the wire to ground until advised further, and the switches at the home station would have been disposed, S to the right, and S_1 to the

left. This provides that when the repairman closes the break, relay R will be energized as a result of completion of the circuit from the home battery to the ground at the distant terminal of the wire. In this case, with the switches disposed as above stated, the vibrating bell sounds the closing of the break.

VOLTMETER TESTS

Voltmeters having a self-contained series resistance of about 2,000 ohms per volt, are used to a considerable extent for line-testing purposes. The various circuit arrangements employed in practice are shown herewith.

MEASURING A GROUND CONTACT

Connect the voltmeter as shown in Fig. 163, with one side of the testing battery to ground. A permanent deflection of the voltmeter pointer indicates a "ground." To ascertain the value of the resistance to ground, note the

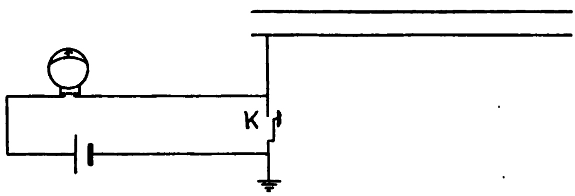


FIG. 163.—Voltmeter method of measuring a ground contact.

reading in volts with key K open. Call this figure V. Close key K, note the altered reading in volts, and call it V_1. Then, where R is the resistance of the voltmeter, the resistance to the ground contact on the line

$$G = \frac{V_1 - V}{V} R.$$

MEASUREMENT OF HIGH RESISTANCE

As in Fig. 164, connect the resistance to be measured at X and close the switch K (thus short circuiting X) and note the deflection of the voltmeter

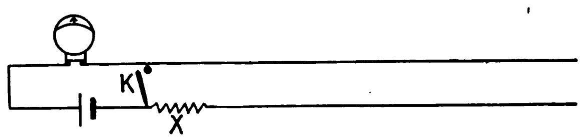


FIG. 164.—Voltmeter method of measuring high resistances.

pointer. Call this V_1. Open the switch K and note the altered deflection. Call it V_2. Then the resistance value desired

$$X = \frac{V_1 - V_2}{V_2} R.$$

R representing the resistance of the voltmeter.

CAPACITY TEST

Connect the voltmeter with a standard condenser C as shown in Fig. 165. First, move the switch to position 1, and note the throw in degrees of the instrument pointer. Call this figure V_1. Then place the switch lever on 2

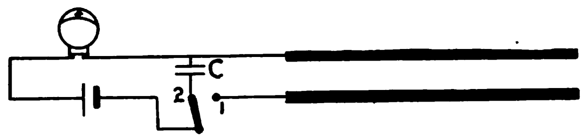


FIG. 165.—Voltmeter method of measuring the capacity of a conductor.

and again note the deflection of the pointer. Call this figure V_2. Then, the capacity of the line $= C \frac{V_1}{V_2}$, where C is the capacity of the standard condenser in microfarads.

MEASURING ORDINARY RESISTANCES

For the purpose of measuring ordinary resistance values, such as instrument windings, lines, etc., connect the unknown resistance at X as shown in Fig. 166. Shunt the voltmeter with a resistance S having a value such that

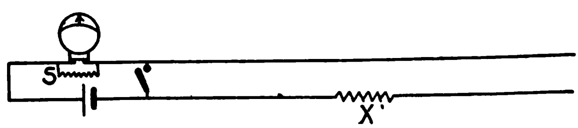


FIG. 166.—Voltmeter method of measuring ordinary resistances.

the combined resistance of the voltmeter and the shunt will have some convenient value, say 200 ohms. (See page 86 for calculating shunt values.) The measurement is then made in the same way as in the case of a high resistance, and the value is

$$X = \frac{V_1 - V_2}{V_2} 200.$$

ROUGH VOLTMETER METHOD OF LOCATING A CROSS

Several ingenius arrangements have been suggested from time to time, with the object of developing a satisfactory voltmeter loop test. It is found in practice, however, that the voltmeter is not as adaptable for making accurate measurements with looped conductors as is the bridge method previously described.

Referring to Fig. 167. If the potential at the point L where the line con-

ductor enters the switchboard is 150 volts, obviously there is a gradual drop of potential along wire A until the point G_1 is reached where the potential has fallen to zero. If a cross between wires A and B exists at the point F the drop of potential at that point may be ascertained by connecting the voltmeter in series with the home end of the wire B and ground.

Then the distance from the testing station to the fault:

$$X=\frac{C-DE}{C},$$

Where C represents the voltage at L
D the voltage at F (or P)
E the distance from L to G.

The wire B must be left open at the distant terminal station, or at an office beyond the cross. It is evident that errors will be introduced, due to any

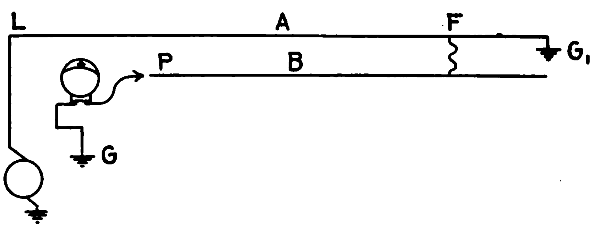


FIG. 167.—Voltmeter loop test.

difference of potential from earth currents between the ground connections G and G_1, to possible high resistance at the fault F, to the resistance of the wire B, and to leakage. The extent to which these factors introduce error is dependent upon the resistance of the voltmeter. If a meter having a resistance of 2,500 ohms per volt is used for the test, results are fairly accurate.

INSULATION RESISTANCE OF LINES

With any form of construction commercially practicable, perfect insulation is not possible. On open aerial lines although electrostatic and electromagnetic induction takes place, there is no current leakage from wire to wire through the air, but at every point at which wires are supported, even with the best construction there will be some leakage from wire to wire and from wire to ground. At every pole there exists a leak to earth. The electrical resistance of this leak is high if the wire is well insulated, and low if the insulation is poor.

At the point of support the wire is separated from the cross-arm or pole by an insulator, and the effective insulation of the line is dependent upon the construction, shape, material and condition of these insulators; also upon the

space along the cross-arm separating the insulator from the pole. Glass of certain grades offers the highest insulation to electrical conduction through its mass of any commercially available material. For the purposes of telegraph insulation, glass does not ideally meet the rquirements, due to the fact that surface conduction plays an important part in leakage from line to wooden support. Glass is highly hygroscopic, and in almost every state of the weather and of the atmosphere it becomes coated with a film of moisture[1] or of gross matter. Certain grades of porcelain, in this regard, meet the requirements more satisfactorily, as porcelain is not as hygroscopic as glass, and rain runs readily from its highly glazed surface.

Many attempts have been made to explain the peculiar behavior of leakage of electric currents over the surface of insulators on which moisture has condensed due to exposure to ordinary atmospheric conditions. Whether the potential applied to the conductor is of one polarity, or is alternating from positive to negative continuously or occasionally, seems to play an important part in varying the electrical resistance of the film of moisture deposited. In some cases it is found that the resistance is enormously greater when the current passes in one direction than when it passes in the opposite direction. Apparently the nature of the oxide formed on the conductor as a result of electrochemical action between the metal of the conductor and the moisture film, undergoes a change as the current in the conductor is reversed. Duration of contact of either polarity, as well as rapidity of reversal, probably are the factors which determine the resistance between the wire and its support, across the surface of the insulator, assuming, of course, that a film of moisture is present. The hygrometric state of the surrounding atmosphere, varying, as it does, naturally accounts for the variations in the thickness of the film of moisture, and this in turn has a direct bearing upon the initial resistance when battery is applied to the line, irrespective of polarity.

The American Telegraph and Telephone Company has considered a clear weather insulation of 10 megohms per mile as satisfactory. The Western Union Telegraph Company has a standard of 50 megohms per mile, while the Postal Telegraph-Cable Company aims to maintain an insulation of 100 megohms per mile in clear weather. Wet weather conditions, however, greatly reduce these figures, and when a drizzly rain and fog prevails for any considerable length of time, it is found that the insulation resistance of lines may drop lower then one megohm per mile. A low-lying dense fog has a most pronounced effect in reducing the insulation resistance of a line, and the hygroscopic characteristics of glass insulators are clearly evidenced when

[1] The large amount of common salt (chloride of sodium) floating about in the form of fine particles in the air results in condensation upon the surface of all exposed bodies. Where these deposits are made upon the surface of insulators, the saline film thus formed is a much better conductor of electricity than is the insulator.

wires are thus weather-bound, by the fact that during a dense fog, should there be a fairly heavy rain-fall lasting a few minutes, the insulation resistance of the line rapidly increases. So much so, that while the rain continues the insulation has been known to closely approach clear weather values. It is hardly likely that the dripping of the rain from the surface of the insulator produces a hydro-kinetic effect which clears the moisture condensed on the inner surface of the petticoat insulator, so that, so far as investigation accounts for the phenomena observed, nothing is explained except that the exterior surface of the insulator has been washed clean.

In addition to insulator leakage, other causes bring about a lowering of insulation resistance, such as contact between wires and limbs of trees, kite strings (the latter when wet sometimes causing leakage from wire to wire), broken insulators, permitting direct contact between wire and cross-arm, surface leakage along the surface of bridle wires resting against cross-arms, etc. All of these avenues of escape are more effective as leaks during wet weather.

The foregoing has been introduced at this time so that an understanding of the various causes which permit leakage of current may be gathered.

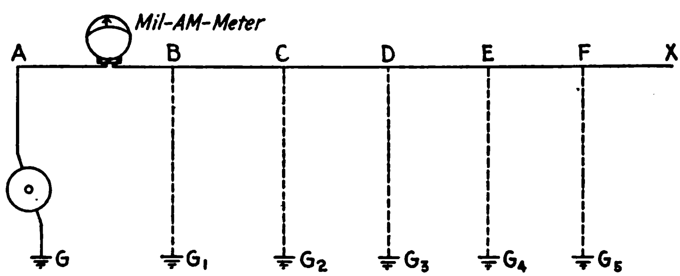


FIG. 168.

The insulation resistance of a line wire may be measured by ascertaining the resistance at the terminal A while the distant end X is open, or insulated, as in Fig. 168.

Under such conditions, the insulation resistance observed does not equal the sum of the several insulation resistances from B to G_1, C to G_2, D to G_3, E to G_4, and F to G_5. Correctly considered the insulation resistance observed is that of the circuits ABG_1, BCG_2, CDG_3, DEG_4, and EFG_5, and at once it is apparent that as each pole or support unavoidably constitutes a leak to earth, the total insulation resistance of the line has the same relation to the joint-conductivity of the various leak paths to ground, as obtain in all other problems concerning joint-conductivity, and which have been considered in an earlier chapter.

MEASUREMENT OF INSULATION RESISTANCE

The voltmeter is used quite extensively in making insulation measurements, but it should be remembered that, inasmuch as the resistance to ground $X=\frac{V_1-V_2}{V_2}R$, as explained in connection with Fig. 164, the resistance per volt of the meter is of the first importance.

A voltmeter having a range of 100 volts, and a resistance of 100 ohms per volt, could not be used satisfactorily in measuring resistances as high as one megohm. The highest resistance that can be measured with such a meter is

$$x=\frac{100-1}{1}10{,}000=990{,}000 \text{ ohms.}$$

It follows that with a 100-volt meter having a resistance of 200 ohms per volt, the highest resistance which can be measured is 1,980,000 ohms.

INSULATION RESISTANCE MEASUREMENTS WITH MILAMMETER

One method of measuring the insulation resistance of lines, which has been used with success, makes use of a milammeter in connection with the quadruplex "long-end" potential of 375 volts negative, as shown in Fig. 169.

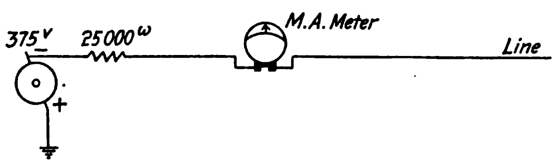


FIG. 169.—Measuring the insulation resistance of a line. Milammeter method.

To measure insulation resistance, the lower scale of a standard milammeter (five divisions equal to one milampere) is used. The meter is inserted in series with a 25,000-ohm resistance unit and connected directly to the line to be measured, as shown.

The 25,000-ohm coil serves to protect the meter from damage in case the line under test is grounded close by. Its presence also minimizes the effects of induced currents, and this results in steadier action of the indicating needle. With a potential of 375 volts and a resistance of 25,000 ohms the milammeter needle travels exactly the full length of the scale, in accordance with Ohm's law. The insertion of any additional resistance, such as that of a line, reduces the amount of deflection.

To minimize the work in computing the insulation resistance in ohms, the reference table given herewith, is used. The column of figures at the extreme left, reading from 30 to 500, refers to length of line in miles, while the row of figures at the top, reading from 1 to 75, refers to divisions deflection on the

	Divisions deflection	1	2	3	4	5	6	7	8	9	10	12	15	17	20	22	25	30	35	40	45	50	60	75
Length of wire in miles	30	56	27	18	13	11	9	7	6	5	5	4	3	3	2	2	2	1	1	1	½	½	¼	0
	40	74	37	24	18	14	12	10	8	7	7	6	4	3	3	2	2	1	1	1	1	½	¼	0
	50	·92	46	30	22	18	14	12	10	9	8	8	5	4	3	3	3	2	1	1	1	¾	¼	0
	75	139	68	45	33	26	22	18	16	14	12	12	8	6	5	5	4	3	2	2	2	1	½	0
	100	185	91	60	44	35	29	24	21	18	16	16	10	9	7	6	5	4	3	2	2	1	1	0
	125	231	114	75	56	44	36	30	26	23	20	20	13	11	9	8	6	5	4	3	2	2	1	0
	150	277	137	90	67	53	43	37	31	28	24	23	15	13	10	9	8	6	4	3	3	2	1	0
	175	324	160	105	78	61	50	43	37	32	28	27	18	15	12	11	9	7	5	4	3	2	1	0
	200	370	182	120	89	70	58	49	42	37	33	31	20	17	14	12	10	8	6	4	3	3	1	0
	225	416	205	135	100	78	65	55	47	41	37	35	23	19	15	14	11	8	6	5	4	3	1	0
	250	463	228	150	111	88	72	61	52	46	41	39	25	21	17	15	13	9	7	6	4	3	2	0
	300	555	274	180	133	105	86	73	63	55	49	47	30	26	21	18	15	11	8	7	5	4	2	0
	350	648	319	210	155	123	101	85	73	64	57	55	35	30	24	21	18	13	10	8	6	4	2	0
	400	740	365	240	178	140	115	97	84	74	65	62	40	34	28	24	20	15	11	9	7	5	3	0
	450	832	411	270	200	158	130	109	94	83	73	70	45	38	31	27	23	17	13	10	8	6	3	0
	500	925	456	300	222	175	144	121	105	92	81	78	50	43	34	30	25	19	14	11	9	6	3	0

lower scale of the milammeter. The figures in the body of the table represent approximately the insulation resistance in megohms per mile. The procedure is as follows: select the figure in the left-hand vertical column nearest to the length of the line under test, and the figure in the top row nearest to the observed deflection in divisions of the milammeter scale, then the figure found in the body of the table at the intersection of these two columns will be the approximate insulation resistance in megohms per mile of the wire measured.

For example: with a line wire 290 miles long, take the nearest mileage shown in the table, viz., 300. With 10 divisions deflection the resistance is, according to the table, 49 megohms per mile. It is possible, of course, to obtain practically the same results by employing much lower potentials, say 110 or 130 volts. In this case the 25,000-ohm series resistance may be omitted. One degree deflection on the upper scale of the milammeter represents five milliamperes current. Five milliamperes with 130 volts indicates a resistance of 26,000 ohms

for
$$R=\frac{E}{I}=\frac{130}{0.005}=26,000.$$

And if the line is 100 miles in length, the insulation resistance per mile

$$=26,000\times 100=2.6 \text{ megohms.}$$

During wet weather the wire under test may have a low-voltage e.m.f. impressed on it due to conduction leakage from neighboring wires which are carrying current. This leakage might be through water-soaked kite strings, along the water-soaked wooden supports, or through limbs or leaves of trees upon which both wires may rest. The presence of foreign current in the conductor, obviously alters the value of the potential applied to it at the testing station: increasing or decreasing the true deflection as the applied and foreign e.m.fs. are of the same or of opposite signs. If this is found to be the case it is well to place to line the polarity which gives the greater deflection.

The case above cited, where the insulation resistance per mile of a 100-mile line was shown to be 2.6 megohms, should not be taken to mean that the various leak paths from line to earth are evenly distributed, but should be regarded as the average for the entire line. In Fig. 168 the resistance of the paths *B*, *C*, *D*, *E* and *F* to ground in each instance may have equal resistances, in which case the leakage will be uniformly distributed along the length of the line. In practice, however, it is more generally experienced that when a low insulation resistance is presented between line and ground, the leak will be found to be unevenly distributed. That is, the leak paths to ground are found to vary greatly in their individual resistance. In most cases where an abnormally low average value obtains, the larger part of the leak will be found to exist at a particular point.

Referring again to Fig. 168. Suppose that when the line is opened at the distant terminal X, the milammeter reading indicates an excessive leak of current to ground. By having the different offices with this wire in their switchboards, in turn open the wire (progressing from office to office in a direction away from X), it may easily be ascertained between which two offices the heavy leak exists. For instance, should the milammeter needle show a deflection of 10 divisions when the wire is open at X only, and change very little as keys are opened at offices between X and F, and F and E, it is evident that the fault exists somewhere between F and A. Should an open key at the office between E and D result in a pronounced reduction in the deflection of the needle, the bulk of the escape will be found at a point somewhere between that office and the office next toward X.

INSULATION RESISTANCE OF DISTANT SECTIONS

There are instances where it is necessary for a wire chief to measure the insulation resistance of remote sections of a line, as from Y to Z, Fig. 170. Two separate insulation measurements are made by either of the methods previously described. The first with the line opened at Y, and the second measurement with the line extending through to Z and opened at that end.

FIG. 170.

Then the insulation resistance of the section Y–Z

$$R=\frac{R_1\times R_2}{R_1-R_2}$$

where R_1 represents the insulation resistance of the section X–Y, and R_2 the insulation resistance of the entire line X–Y–Z. The insulation resistance of the section Y–Z in megohms per mile,

$$X=\frac{R\times D}{1,000,000}$$

where D represents the length in miles of the section Y–Z.

CONDUCTIVITY MEASUREMENTS

The Wheatstone bridge method of measuring the conductivity of a line was explained in connection with Fig. 157, and that method should be used where accurate measurements are desired.

Voltmeter-ammeter Method.—Approximate figures may be obtained

more quickly by means of the voltmeter-ammeter method as follows: the wire to be measured is grounded at the distant station and an e.m.f. of about 125 volts applied to it at the testing station. Through the medium of the spring-jack at the switchboard there is included directly in the circuit a milammeter as shown in Fig. 171. After the value of the current flowing has been noted, the milammeter is disconnected from the circuit and a voltmeter with one terminal grounded, is connected with the line contact of the spring-jack. The reading in volts is noted. Thus,

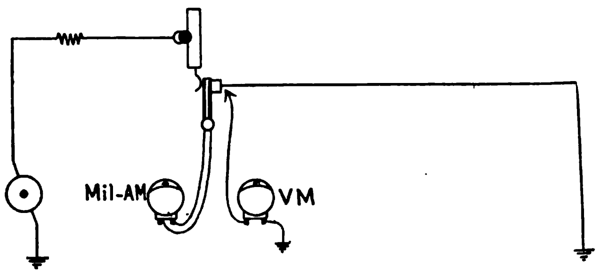


FIG. 171.—Measuring the conductivity of a line by the voltmeter-ammeter method.

having the current and voltage values obtaining in the circuit, the resistance may be calculated by Ohm's law, or the conductivity of the line, in ohms

$$R = \frac{E}{I\text{ (in milliamperes)}} \times 1{,}000.$$

The two readings of voltage and current should be taken, one immediately after the other, in order to minimize the probability of error.

MISCELLANEOUS TESTS

LOCATING ALTERNATING CURRENT CROSSES

A method of locating alternating current crosses on telegraph lines, suggested by A. J. Eaves, is illustrated in the schematic diagram, Fig. 172.

Disconnect the battery wires of a Wheatstone bridge set at *c* and *d*, and ground the point *c* through a resistance *AR* sufficient to reduce the incoming alternating current below the danger point, and then substitute for the galvanometer of the set an alternating current milammeter, shunted with about 10 ohms resistance, *S*, as a protection to the instrument. Balance the bridge by inserting resistance in the rheostat portion of the bridge until the needle points to zero, on the lower scale of the milammeter. This indicates that no current flows between *f* and *g*. Then half of the resistance of *R* will be equal to the distance in ohms from the point where the crossed wire is looped with the good wire to the alternating current cross, where the two wires are of

approximately the same resistance. To determine the distance in miles from the test station to the cross, make a loop measurement of the good and crossed wires before the battery wires are disconnected from the bridge, and use the Varley formula:

$$Z=\frac{R_1-R}{2},$$

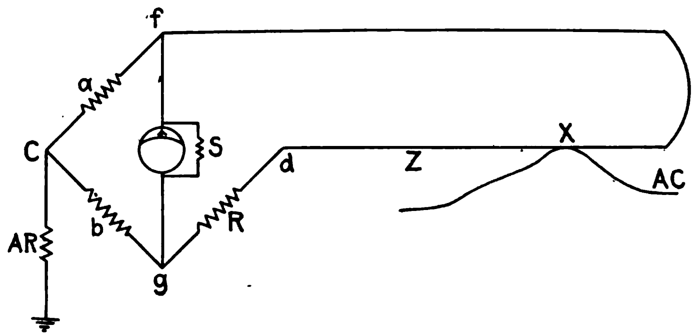


FIG. 172.—Method of locating a cross between a telegraph line and an alternating-current line.

where Z = resistance from testing station to cross,
D = length of the loop in miles,
R_1 = resistance of loop in ohms,
R = resistance of rheostat when bridge is balanced.
Then the distance in miles from the test station to the cross is

$$X=\frac{Z\times D}{R_1}$$

By using a telephone receiver instead of an alternating-current milammeter, the same result can be obtained by inserting resistance in the rheostat R until no noise, or until minimum sound is heard in the receiver.

WESTERN UNION PROPORTIONAL TEST SET

Within recent years several different makes of testing set have been introduced, which have been designed with the object of reducing to a minimum the amount of calculation necessary to locate faults.

A set of this kind, which has been adopted by the Western Union Telegraph Company for the use of linemen and cable testers has its circuits arranged as shown in Fig. 173. This set consists of a simplified rheostat, a galvanometer and a battery contained in a box 7×9×5 in. in size. The component parts of the apparatus, with their connections, are shown in Fig. 173, where GS is a galvanometer shunt, R a rheostat with a radial contact arm, BK a battery key, and SK a shunt key.

Locating a Cross or a Ground.—Select a good conductor having the same gage as that of the faulty wire, preferably one running along the same route, or in the same cable. Connect the good conductor to the binding

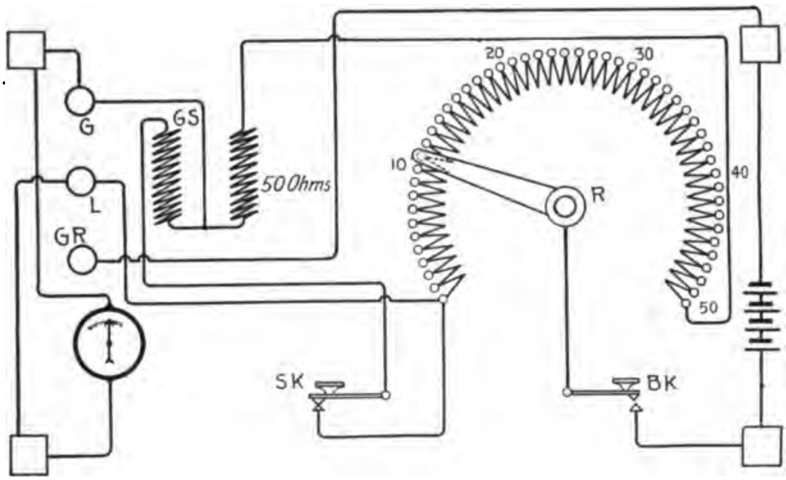


FIG. 173.—Circuits of the Western Union proportional test set.

post *G* of the set, and the faulty wire to the binding post *L*. Have the distant station or testing point connect the ends of the two wires together as in looping. If the trouble is a cross, connect the other crossed wire to the binding post *GR*. If a ground, connect the post *GR* to the home

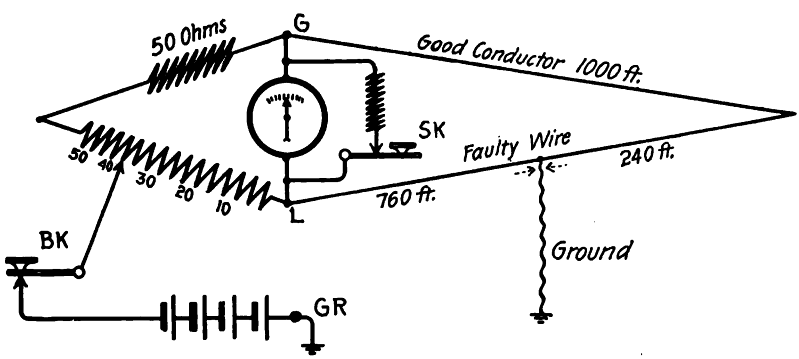


FIG. 174.—Locating a ground contact with the W. U. proportional test set.

ground. Move the radial arm over the contact buttons around the circle until a point is reached where closing the key *BK* does not result in a deflection of the galvanometer needle. Now close both battery and shunt keys, and if the needle is deflected, move the arm to a contact where the

needle shows the least movement. As the contact buttons are numbered from 1 to 50, multiply the number of the button at which minimum deflection is observed by the total length in feet of the loop, and divide by 100; this will give the distance in feet from the testing point to the fault.

Example: in locating a ground, suppose a loop is made up having a total length of 2,000 ft., Fig. 174, and a balance is obtained when the arm rests on contact No. 38, then the distance to the fault is

$$\frac{38 \times 2000}{100} = 760 \text{ ft.}$$

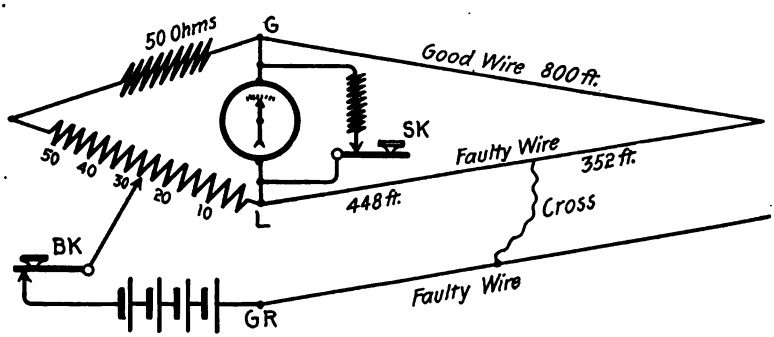


FIG. 175.—Locating a "cross" with the W. U. proportional test set.

If in locating a cross, a loop is made up having a total length of 1,600 ft., as in Fig. 175, and a balance is obtained when the arm rests on contact No. 28, then the distance to the fault is

$$\frac{28 \times 1,600}{100} = 448 \text{ ft.}$$

INEQUALITIES IN LINE RESISTANCE

Fault locating by loop methods; generally is based on the assumption that the conductors employed are of uniform resistance per unit length. In many instances this is not true, and unless the wire inequalities balance each other, the working out of formulæ will not always give exact locations. Fortunately, in most cases inequalities are distributed so that one compensates for another, thus evening up the resistance to a value approximately that of the calculation. Inequalities may consist of introduced resistances, such as those resulting from poorly soldered sleeves, variations in gage of the conductors used, and variations in temperature of different portions of the line.

USING CONDUCTORS OF MIXED GAGES

In those instances where it is necessary to use cable conductors of different gages in making up loops for measurement purposes, it is customary to

compute a scale of coefficient values, such for instance as might be used to change a conductor of a certain gage into resistance-feet-equivalents of the other wire available.

Where conductors of 14 and 16 gage are concerned, the desired ends may be attained by multiplying the given number of feet of 16 gage by the coefficient 1.59, which changes it into the number of feet that would be required to make up the same resistance in cases where a 14-gage conductor is used. No. 14 gage likewise may be changed to 16 gage, for the purposes of measurement, by employing the coefficient 0.625.

TELEPHONE RECEIVER TESTS

For making qualitative tests, the telephone receiver has, due to its great sensibility to weak currents, come into quite general use in locating faults in cables.

A tester who has had experience with the telephone receiver as a testing instrument recognizes several different tones or "clicks" when the receiver is connected directly in a circuit supplied with battery, or when the receiver is connected inductively with another circuit.

When a receiver and a source of current are directly connected through a low resistance, each time the circuit is closed and opened, the diaphragm of the receiver is attracted and released, respectively, and this movement of the diaphragm results in an audible click varying in intensity according to the amount of resistance of the circuit. The click in this case is quite sharp and pronounced and is recognized as a closed-circuit or "battery" click.

In cases where the receiver and the battery are connected through a high resistance, say, in the neighborhood of a megohm, the click will still be audible, but not intense or sharp. In a circuit of this kind the sound heard is recognized as a "leak" click.

If a receiver is connected in circuit with a long aerial or cabled conductor, even if the wire is open at some distant point, a sound is heard in the receiver which is recognized as a "capacity" click. It is caused by the charging or discharging of the line through the coils of the receiver. Still another characteristic click heard in the receiver is recognized as due to induction from neighboring parallel circuits which are carrying interrupted currents, or currents which are being reversed in polarity at regular or irregular intervals.

In several tests heretofore described, where a telephone receiver was substituted for the galvanometer in "bridge" measurements, the receiver was availed of to indicate "no current" or minimum difference of potential. In the "tone" tests now under consideration the receiver is required to indicate the conditions obtaining in the circuit being tested, by differences in the volume of sound produced, or by characteristic "tones" regardless of volume.

TESTING FUSES WITH THE RECEIVER

If the receiver is equipped with a double-conducting cord having two free terminals, fuses may be tested without removing them from the fuse blocks, simply by touching the two terminals of the cord to the fuse terminals. The "battery" click indicates that the fuse is burned out, or open.

TESTING LINE CONDUCTORS

In testing ground-return circuits, the receiver may be connected in series with a battery which has one terminal grounded as in Fig. 176. If the battery click is heard in the receiver when the other terminal of the receiver is connected to the line wire, the indication means that the conductor is grounded. The "capacity" click would indicate that the circuit is "open," while the "leak" click would indicate that the line is grounded through a high resistance. Obviously the strength of the "capacity" click would indicate roughly the distance to the point at which the line is open, and the strength of the "leak" click would indicate roughly the resistance value of the leak to ground.

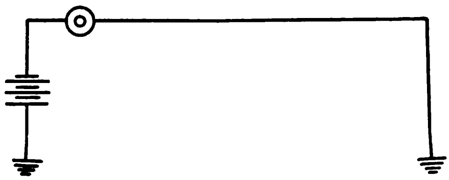


FIG. 176.—Circuit testing with telephone receiver.

In cabled conductors crosses may occur between individual circuits due to break-down of the insulation between the wires, to wearing away of the insulation due to vibration, to crystallization of the lead sheath which permits moisture to enter, to lightning and to various other causes. Grounding of a conductor occurs when an uninsulated portion of the wire comes into contact with the lead sheath.

LOCATING GROUNDS AND CROSSES WITH THE RECEIVER

The testing circuit is made up of a dry-cell battery and a telephone receiver in series, one end of the circuit being connected with the sheath of the cable, while the other terminal of the circuit is placed in contact with the wire to be tested. At the end of the cable from which the test is being conducted, all other wires should be "bunched" and connected with the sheath. At the distant end of the cable all wires are left "open" then, touching the metal tip of the receiver cord to the various conductors will quickly develop whether any of them are crossed or grounded. The "click" peculiar to each kind of fault indicates the nature of the interruption.

CONTINUITY TESTS WITH THE RECEIVER

Tests for continuity require that all wires be bunched at the distant end of the cable and there connected to a separate wire in another cable, which

extends back to the point from which the test is being made. The spare wire is connected to one terminal of the testing circuit as shown in Fig. 177. The other terminal of the testing circuit, then may be connected successively to the ends of the various conductors at the testing station.

If, when the metal tip of the receiver cord is repeatedly touched to the end of a wire, the clicks continue without diminishing in intensity; the circuit is continuous, while the cessation of the clicks after a few contacts have been made, indicates that the circuit is open. The two or three clicks heard in this case, are due to the battery of the testing circuit charging the conductor under test.

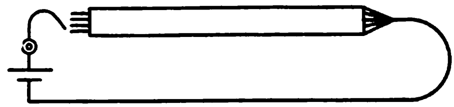


FIG. 177.—Continuity test with telephone receiver.

Continuity tests are frequently made with a vibrating bell or a buzzer in place of a telephone receiver, and although more battery is required in making the test, the buzzer gives a more definite signal, and is not likely to record static impulses.

FAULT-FINDERS

There are several telephone "fault-finder" testing sets in common use which are based on the principle that if an interrupted current is continuously sent out over cabled conductors, the "tone" peculiar to the interrupted current thus impressed on the conductors may be detected at any point along the cable by means of exploring coils, or detector coils especially designed for the purpose.

Among these might be mentioned the Matthews' "Telafault," and the "Wireless Trouble Finder."

THE MATTHEWS' TELAFAULT

The Telafault is a self-contained cable testing set, designed for locating trouble in telegraph and telephone cables. By means of this set, low resistance crosses, grounds and shorts, can be readily located by the cable tester or trouble-man, and where the test is properly made, the fault can be located closely.

The schematic arrangement of the circuits of this test set is shown in Fig. 178. Included as a part of the set, there is an "exploring" coil, the terminals of which are connected with a telephone receiver fitted with a head-band. Closing the battery switch S starts the interrupter, and when two cable conductors are connected with the binding-posts A and B, an interrupted current is sent out, due to the opening and closing of the vibrating armature V. The exploring coil, Fig. 179, is then moved along the sur-

face of the cable sheath, and the sound due to induction from the interrupted current is heard in the receiver.

When the point is reached at which the fault exists, the sound in the receiver will cease or become very feeble. If now the coil is moved still further along the cable sheath, there will be practically no sound, while on the section of cable between the fault and the point from which the interrupted current is being sent out there will be a pronounced sound in the

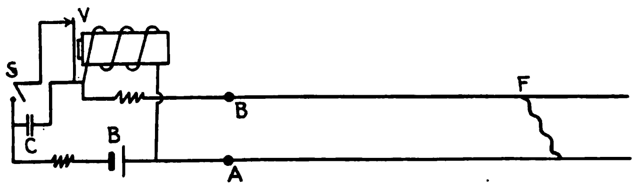


FIG. 178.—Circuits of the "Telafault."

receiver. This enables the tester to locate the trouble within narrow limits. The exploring coil is so designed that by proper manipulation all return currents in the sheath of the cable tending to interfere with exact location of the fault are effectively neutralized.

In small cables, having 100 conductors or under, sometimes it is possible to remove "shorts" and "grounds" without opening the cable. When the trouble has been located at a definite point, if the cable is bent back and forth several times, the movement of the conductors thus produced frequently breaks the contact and clears the trouble.

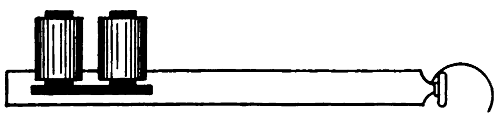


FIG. 179.—Exploring coil of the Telafault.

The vibrator should be adjusted to operate at about 600 or 800 vibrations per minute. The frequency may be adjusted while the exploring coil is held in the neighborhood of the magnets of the vibrator, with the receiver placed to the ear. The tester should familiarize himself with the particular frequency of the currents sent out, so that he may readily recognize the testing signal when the exploring coil is held close to the sheath of the cable containing the conductors being examined.

The external connections are as indicated at *A–B* Fig. 178. For locating grounds, connect *A* with the cable sheath or with the earth, and *B* with the faulty conductor. In locating crosses, connect the ends of the crossed wires to the binding-posts *A* and *B*. In all cases the ends of the wires should be left open at a point beyond the trouble. Then, with the interrupter in operation, the exploring coil is moved along the cable. In aerial cable measurements, tests may be made from pole to pole until the fault is located between two cer-

tain poles. Then if the messenger wire is ridden so that the coil may be applied directly to the cable sheath along the span, the fault may be located within an inch or so. Usually it is best to climb only every third or fourth pole until the trouble is located within narrow limits, thus obviating the necessity of climbing every pole to make contacts. Of course, where a Wheatstone bridge set is available, the approximate location of the fault should be determined by means of the Varley, Fisher, or any of the loop tests, after which the exploring coil may be employed to exactly locate the point at which the fault exists.

The magnitude of the sound in the exploring coil depends upon the strength of the field produced in the faulty wire by the interrupted current, and upon the intervening distance between the conductor in trouble and the lead sheath.

Should the pair of wires in trouble be in the center of a large cable, the sound in the receiver due to induction will not be as loud as if they were located in a layer near the surface. An average case would be where the con-

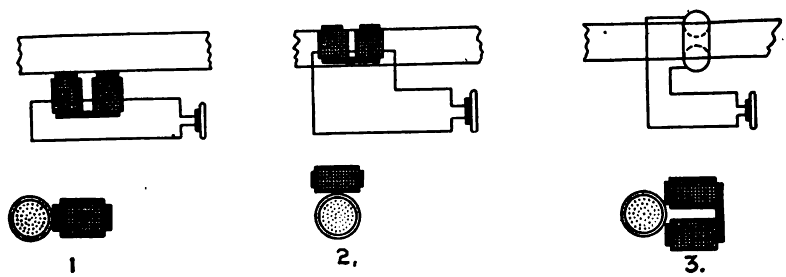


FIG. 180.—Various positions of exploring coil on sheath of cable.

ductor or conductors in trouble are located midway between the sheath and the core of the cable, and this condition with the regular ten-volt interrupter current employed permits of a limiting resistance, for grounds, from the interrupter to the fault and return of 100 ohms. For "shorts" the limiting resistance is about 500 ohms. With a 50-volt battery, the limiting resistance, for grounds, is 600 ohms, and for shorts 800 ohms, or thereabouts. The Telafault has a "heat coil" adjunct which automatically opens and closes the interrupter circuit. This arrangement permits of sending out a prearranged series of impulses at regular intervals, and which may be readily distinguished from any other possible induced current affecting the wires in the cable.

In attempting to locate grounds or crosses with the exploring coil, the coil should be placed on the sheath as indicated in position 1, Fig. 180. The spiral lay of the conductor may easily be followed along the cable by means of the "tone." This insures abrupt cessation of the sound in the receiver when the fault has been passed. Position 2, also, may be used for the same

purpose as position 1. Position 3, while it gives the greatest volume of sound in the receiver, should not be used after the fault has been nearly located, for should the cable sheath or the conductor be grounded, sound may be heard beyond the fault.

The instrument should be connected at a cable box apparently nearest the trouble in order to reduce resistance to fault. In case of wet cable or where several conductors are grounded in one place, as many conductors as convenient should be "bunched" at *B*, Fig. 178.

THE WIRELESS TROUBLE FINDER

There are several different makes of "wireless" fault-finder, among which might be mentioned that manufactured by the Electric Specialty

FIG. 181.—Queen and Co.'s "wireless" test set.

Company of Cedar Rapids, Iowa, and a similar instrument manufactured by Queen & Co., Philadelphia.

The former is extensively employed in the cable testing service of both telephone and telegraph companies, and its operation is practically the same as that of the "Telafault" previously described.

In using the wireless tester for locating faults, a working conductor may be employed as one side of the testing circuit by inserting a condenser in series with the working conductor used.

Figure 181 is a photographic reproduction of the fault-finder manufactured by Messrs. Queen & Co.

CHAPTER XI

SPEED OF SIGNALING

CIRCUIT EFFICIENCY

So far in this work, the only method of telegraph line operation considered is that described in Chapter VII, dealing with single Morse transmission, by means of which one message is sent over a line in one direction at a time.

The various requirements of construction and of operation which affect the speed of signaling constitute the factors which in turn, in large measure, determine efficiency of circuit operation.

The nature of the service is such that line wires may have lengths of from a few hundred feet to hundreds of miles, and in view of what was stated in the preceding chapter in regard to current leakage from line to ground, where aerial lines are concerned, it is apparent that the longer the line the greater will be the total leak in a particular circuit.

Obviously, too, the longer the line, the greater will be the total ohmic resistance between terminals, and the greater the electrostatic capacity of the circuit. The fact that increasing the length of the line involves increases in the values of these various speed-limiting factors at once suggests that there are fairly well-defined critical lengths of line which can be operated at a satisfactory degree of efficiency.

Naturally there are limitations to the amount of voltage which may be applied to a wire. For, although the current strengths required to operate the usual type of receiving instrument are of small volume, the comparatively long lengths of line wire stretching between stations or terminals constitute resistances which in themselves greatly reduce the current which would be available from a given source of e.m.f. on shorter circuits.

Among the reasons which make it advisable to limit the applied e.m.f. are, first, safety of employees handling the operating instruments and switching apparatus; second, fire risks at terminal offices where battery is applied to lines; third, the deleterious effects of electrostatic induction between neighboring conductors carrying high voltage; fourth, possible damage to instruments and apparatus in case of short circuits, or in case line wires become grounded near the terminal station; fifth, destructive sparking at contact points of "keys" and transmitters. Also, where line wires are carried through aerial or underground cables, the insulation between individual conductors carrying high voltages is constantly subject to break-down.

In view of the above cited considerations it is obvious that it is not feasible to increase the length of satisfactorily operative circuits simply by applying increased battery power.

So far as speed of signaling is concerned, more may be accomplished toward increasing the efficiency of a line by substituting a conductor having higher conductivity per unit length, and by bettering the insulation obtaining throughout the length of the circuit between line and ground. Of course, in these respects, too, there are imposed limitations which concern material and dimension of conductor, but these are determined by what is commercially practicable.

When we investigate the various causes which make it advisable in practice to divide long circuits (say from New York to San Francisco) into "repeater" sections of approximately 500 miles, we learn that conductor resistance, leakage conductance, conductor capacity, and conductor inductance, are the factors which limit the length of circuits which may be operated at high speed, to 500 or 600 miles. Theoretically, the most satisfactory conditions in telegraph circuits obtain when the conductor resistance is at a minimum, when leakage conductance is low, when the electrostatic capacity of the line is lowest, and when the inductance is lowest.

The reader here is referred to Chapter VI under the heading "Electrostatic capacity of conducting wires" in connection with Figs. 68 and 69, and wherein it is stated that electrostatic capacity has the same effect as if it retarded or delayed the initial appearance of current at the distant end of a line. And further, "In the transmission of telegraph signals over a wire, the circuit is closed and opened four or five times per second, and in the case of long lines, the effect of electrostatic capacity is to considerably curtail the number of impulses or signals which may be sent over the wire in a given length of time."

If the line wire instead of being suspended 30 or 40 ft. above the earth were suspended but a few inches above the ground, then, due to the reduced dimension of the intervening dielectric (the air) between the wire and the ground, the electrostatic flux would be much more intense, and regardless of other factors, there would be a marked decrease in speed.

The effect of electrostatic capacity in reducing the number of impulses which may be transmitted over a wire in a given period is sometimes referred to as retardation and, consequently, as the electrostatic capacity increases, retardation is increased proportionately. The impulse impressed on the line at the sending end is required to charge the entire surface of the conductor before it can affect any signaling device at the receiving end of the line. Furthermore, when the circuit is opened the charge accumulated on the surface of the conductor has to escape or be withdrawn from it before the signaling instrument at the receiving end releases its armature, or at least before the effects of electrification will cease to be in evidence at the receiving end of the line.

Thus it may be seen that there is an advantage, so far as rapid signaling is concerned, in having a certain amount of leakage conductance from line to earth, provided it is properly distributed along the length of the line, for, when a key is opened, instead of having to wait until the accumulated charge travels the full length of the conductor to find an outlet, the distributed leakage paths present near-at-hand avenues of escape and thus "clear" the line of the charge more quickly. The objections to leakage, however, still hold good, and a critical value is soon reached where the advantages resulting from reduced retardation are offset by the consequent reduction in current volume in the coils of the receiving instrument, which follows when the leakage is excessive.

The truth of the matter is, that with the usual standards of line insulation maintained, the current flow in a line is never wholly interrupted. This means that main-line relays whose armatures are withdrawn from the closed position by means of retractile springs are so adjusted with respect to "marking" and "spacing" positions of the armature tongue that the relay operates

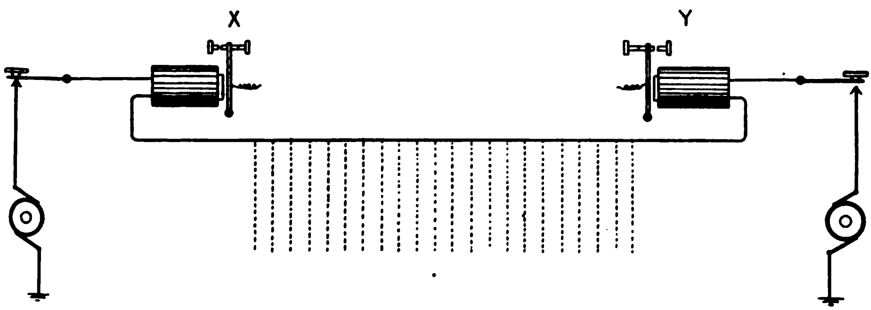


FIG. 182.—The effect of leakage conductance in the limiting strength of operating and releasing currents.

on a "margin" of current strength, somewhere between maximum and minimum current flow. Maximum current value obtains in the circuit when the keys at both ends of the circuit are closed, and minimum value when either key is opened.

Referring to Fig. 182: When the key at X is open, the strength of current traversing the coils of the line relay at Y will depend upon the leakage conductance of the combined leakage paths to earth via the insulating supports, and other avenues of escape to earth along the length of the line toward X. If the line conductor extending between X and Y were perfectly insulated, it is evident that opening the key at X would completely interrupt the current in the relay at Y, but the fact that in practice there is a certain amount of leakage to earth means that when the key at X is opened, the battery at Y still has a circuit through the relay at Y by way of the various leakage paths to earth and back to the other terminal of the battery at Y.

The retractile spring adjustment of the usual type of single main-line relay and of the "neutral" (common side) relay of quadruplex systems, provides a means whereby the relay may be made to release its armature when the current traversing the relay coils has fallen in strength below a certain value. Thus we realize the importance of high insulation resistance of line wires, where high speeds of signaling are involved. The less the leakage conductance, the more abrupt will be the cessation of current in the relay coils. On lines which have appreciable leakage the opening of a key results simply in reducing the current volume flowing. Practically, this means that the retractile spring attached to the armature of the relay must be given a tension which will cause it to withdraw the armature when the current strength in the relay coils has fallen below a certain value, and which will be overcome when the current strength has increased to a certain value.

To illustrate: suppose that the maximum current strength in a long single Morse circuit is 75 milliamperes. It is there required that the relay armature shall be attracted when the current has built up to a strength of 75 milliamperes, and average leakage conditions impose the requirement that the armature shall be released when the current has fallen to a value of, say, 20 or 25 milliamperes. This, of course, is taken care of by the retractile spring adjustment, but it is noteworthy that in either case the operation of the relay in reality depends upon variations in current strength, and not as it would appear theoretically, upon maximum current strength and upon complete interruption or cessation of current in the circuit.

It is then, apparent that the "releasing" current will have a greater strength as the leakage conductance is greater, and—as when the line is immersed in a heavy fog, or when the insulation resistance of the line has been permitted to fall to a low value—the length of circuit which may be satisfactorily operated, even at ordinary hand speeds, will be diminished accordingly.

THE EFFECT OF CABLED CONDUCTORS UPON SPEED OF SIGNALING

As has been pointed out, the effect of bringing an overhead line wire into close proximity with the earth (thus increasing the electrostatic capacity of the conductor) results in increased retardation. Therefore when a number of conductors are insulated and made up in the form of a cable, a condition is created practically identical with that which exists when an individual conductor is suspended close to the surface of the earth. That is, the electrostatic capacity of each conductor in the cable is increased, due to the proximity of neighboring conductors. This is true whether the cable is suspended at the top of a pole line 40 ft. above the earth, or whether the cable is buried beneath the surface of the earth.

At the outset it is evident that telegraph circuits made up of copper conductors carried in cables are much more concerned with the factors of capacity and resistance than with leakage and inductance. A cabled con-

ductor is continuously supported throughout its entire length, but the insulation resistance of the support is practically constant, as it is independent of atmospheric conditions. It is true that tests would show that there is measureable leakage conductance, but for all properly constructed cables the leakage is not sufficiently appreciable to be considered as a factor in limiting the receiving end current volume.

As was stated in a previous chapter (page 124) the presence of inductance in a circuit tends to choke currents which alternate in polarity. The presence of inductance in a circuit also has a retarding effect upon direct currents when initially applied. When a telegraph circuit which is operated from a source of direct current is opened or closed, that is, while the current in the circuit is diminishing or increasing, the presence of inductance in the first case has the effect of prolonging the current, and in the second case has the effect of delaying the increase of current strength in the circuit.

Elsewhere it has been stated that when a circuit carrying current is closed (completed) a magnetic field is established about the conductor, which, as long as the circuit remains closed, may be regarded as stored about the conducting wire. The presence of inductance in a circuit is manifested by the appearance of a bright bluish spark at contact points due to the so-called extra current when the circuit is opened. The spark represents the stored energy of the magnetic field, which produces a direct current at the instant the circuit is opened. When the circuit is "made" or closed, there is no spark produced at the contact points of the key due to self-induction as the extra current is then in an inverse direction, and is engaged in the work of storing energy around the conductor in a direction proceeding away from the point where the charging current is applied to the wire.

A formula applicable to direct currents, for determining the current value of the energy stored in the magnetic field surrounding the conductor, and which has long been the basis of such calculations, is $1/2\ LI^2$, in which L represents inductance in henries, and I the current in amperes. This is apparent from the fact that while the magnetic field gradually increases to LI lines, the mean value of the current would be $\frac{I}{2}$.

Helmholtz' law (page 95) in its application to telegraph transmission problems points to the conclusion that where the inductance is small as compared with the ohmic resistance of the circuit, the amount of retardation chargeable to inductance is inappreciable.

With leakage and inductance eliminated as important factors, there are left, so far as cabled conductors are concerned, the factors capacity and resistance.

THE KR LAW

The constantly increasing amount of aerial and underground cable which is taking the place of open-pole line construction means that more or less

extensive sections of trunk lines pass through cables, and this results in placing overland circuits in the category of cable circuits, at least through those sections where overland wires are carried through cables.

In cable operation it is understood that the time required to transmit a given number of impulses varies almost in direct proportion to the capacity and the resistance of the conductor, which in any given case would give a quantity KR. And, as in most cases capacity and resistance are proportional to the length of the cable, it is evident that the resulting retardation is proportional to the square of the length of the cable. Suppose, for example that it is desired to ascertain the value of the quantity KR in a cable conductor 100 miles long having a resistance of 20 ohms per mile and a capacity of 0.3 m.f. per mile, then

$$(20 \times 100) \times (0.3 \times 100) = 60{,}000, \text{ the } KR \text{ of the circuit.}$$

In this connection it is interesting to note the KR value of an overhead line suspended in the usual manner upon insulators. A No. 9 copper wire, for instance, with a resistance of 4 1/5 ohms per mile, and a capacity of approximately 0.012 m.f. per mile, would have, for a 100-mile line, a KR of

$$(0.012 \times 100) \times (4\ 1/5 \times 100) = 504.$$

For the purpose of emphasizing the relation which the quantity KR in cabled conductors has to transmission efficiency, we might consider the effects produced by it in cables used for telephonic purposes, where practically all of the transmission losses experienced are attributed to that quantity.

In one of his electrical papers John B. Adams states that the transmission loss may be regarded as being proportional to the square root of the product obtained by multiplying the resistance of the completed circuit by the mutual capacity of the circuit in farads, or

$$\text{Loss in transmission} = K\sqrt{R \times C}$$

in which R represents the loop resistance in ohms,
C the mutual capacity in farads,
and K a constant approximately equal to the average frequency of voice currents.

The application of this formula in comparing the relative transmission losses of conductors of different gages (where metallic circuits and mutual capacity are involved) indicates that the loss in transmission is not directly proportional to the KR of the circuit. In the operation of telegraph lines, where grounded circuits generally are employed, and where the form of capacity encountered is somewhat different from that considered in the above formula, the quantity KR may safely be taken as the criterion of the speed of signaling through cables.

Measurements made on rubber-insulated and on paper-insulated cables used in telegraph service show an average capacity per mile per conductor for rubber covered 0.62 m.f. and for paper 0.10 m.f.

A cabled conductor of No. 14 gage when rubber covered for a length of 1 mile is as detrimental to telegraph transmission as a length of 2 1/2 miles of paper-insulated conductor of the same gage. And in general, for any length of conductor the loss is proportionate with length.

A No. 9 copper wire weighing 210 lb. per mile, suspended on poles and having a capacity to ground of 0.012 m.f. per mile for a line length of 130 miles would have a telegraph transmission efficiency equivalent to 1 mile of rubber-covered cabled conductor.

TELEGRAPH SPEED IN WORDS PER MINUTE

With reference to the number of words that can be transmitted over a given line in a given time, the speed of signaling depends considerably upon the methods of transmission employed. If signals were transmitted by regularly periodic pulsations, or by alternations of current continuously impressed upon the line, the transmitting apparatus could be designed to meet the transmission efficiency of the circuit, as in the case of alternating-current lighting and power operations.

It is well known that hand transmission is quite inefficient, and the number of words per minute that can be sent over a given line varies with different operators—this, aside from the relative skill of different operators in rapidly manipulating the sending key. A certain operator, for instance, may be capable of sending 40 words per minute over a short line (where the total insulation of the line is high, and where the variations in operating and releasing currents are a maximum) while on a long circuit he may find it necessary to slow down his speed to, say, 20 words per minute in order properly to actuate the receiving relay at the other end of the line. Another operator, who can transmit but 30 words per minute over the short line, may be able to keep up this same speed over the long circuit, and still have his signals reach the receiving end firm and strong.

This brings to notice the fact that hand transmission is irregular; meaning that the transmission capabilities of the circuit are not always availed of to the fullest extent. The difficulty is that in many cases the duration of contact is not long enough. The "dot" elements of the letters may be made too rapidly, and signaling time may be lost in unnecessarily long spacing. These inaccuracies of transmission are peculiar to hand sending, and in large measure are obviated by machine transmission, such as that employed in Wheatstone operation.

The Morse alphabet consisting of 26 English letters is made up of "dots" "dashes" and spaces. The basis of the alphabet is the dot. A dash is

equivalent in length to three dots. The space between the elements of a letter is equal to one dot. The space between the letters of a word is equal to three dots, and the spaces between any two words is equal to six dots.

The American Morse alphabet (26 letters) has a total of 77 elements, with an average for each letter of 2.9615 elements; or for a five-letter word an average of 14.807 elements.

The Continental Morse alphabet (26 letters) has a total of 82 elements, or 3.1538 average signals per letter, and 15.769 average signals per average word of five letters.

Including spaces, the average five-letter word (American Morse) contains 36.59 dot elements, or practically 5 per cent. less than a five-letter word composed of Continental signals. A sending speed of 25 words per minute means 394.22 signals per minute in the case of the European alphabet, and 370.17 signals per minute in the case of the American Morse. The last two estimates are exclusive of space elements between words. All of the above figures are obtained by simple multiplication, and are based on lengths of dot, dash, and space agreeing with the scientific arrangement of the alphabet.

With manual transmission it is found that length of dot, dash, and space does not accurately agree with that intended, the result of which is that a considerable amount of signaling time is lost in unduly prolonged spacing, and this constitutes so much dead time. When it is shown that the calculated number of words per minute have been handled in a given instance, it means simply, that the extra time consumed in spacing has been used up at the expense of the signaling elements—that their duration of contact has been cut short.

SEMI-AUTOMATIC TRANSMITTERS

Within recent years semi-automatic sending machines in various forms have been extensively introduced. One of these machines the Yetman, is operated by means of a type-writer keyboard, and is designed to transmit perfectly formed Morse characters, provided the contact disks are kept clean. If these disks are permitted to accumulate dirt, or foreign matter of any kind, or to become rough or uneven of surface, the transmitted signals may be "light" owing to the introduction of high resistance, or to drop out entirely owing to failure of contact. This machine is operated in the same way as an ordinary type-writer, simply by depressing the type key of the letter it is desired to transmit. Intelligent operation and good judgment are required, however, in order to effect even continuous transmission, as it is evident that a letter "B" (dash and three dots) should be given a longer time to form than a letter "E" (one dot).

The various transmitters of the Mecograph, Vibroplex type, in forming

dashes require as many movements of the hand as are required with the ordinary Morse key, while any required number of dots are made by holding the lever on one side, allowing the lever to vibrate and thus regularly close and open the main-line circuit until the desired number of dots have been formed.

It may be that a semi-automatic transmitter can be developed which will meet the needs more satisfactorily than any so far introduced, for although the sending machines at present in use have surely made for increased speed of signaling, they have, in many instances, been the cause of poorly founded reflections being cast upon the electrical efficiency of a certain class of circuits.

The difficulty is that automatic sending devices frequently are so adjusted that the dot portions of the letters are made at a rate of 50 to 90 words per minute, while the actual speed in words per minute attained by the operator may amount to less than 30. This being the case, there exists in a more aggravated form, the same loss in signaling time on account of undue prolongation of the spacing elements, with the added defect that the dots are more "clippy" and the duration of the dot contact more transitory and fleeting.

It is plain, then, that when a circuit has been designed to have a certain efficiency, whether or not that efficiency is attained depends greatly upon the character of transmission employed in its operation.

SPEED OF SIGNALING OVER OPEN AERIAL LINES

The fact that most main telegraph offices are located in the heart of the business section of towns and cities means that most of the long trunk circuits, in the aggregate, pass through a considerable amount of underground cable, as modern conditions are such that electric wires are required to be placed underground in cities of any considerable size. Circuits between New York and Chicago (1,000 miles) pass through from 20 to 50 miles of cable, depending upon the route taken. As the tendency is to increase the amount of underground cable used, most long-distance circuits have to be regarded as made up of part underground and part aerial line, and any question of circuit efficiency must take into consideration the factors obtaining in each form of construction. In any given case, the great preponderance of open aerial conductor over that placed underground permits of covering much greater distances than if the circuit throughout its entire length were contained in a cable. Where overhead open lines are concerned, the factor of leakage enters as a most important consideration, and the *KR* law no longer holds good as the only quantity or factor involved.

"CROSS-FIRE"

Another disturbing factor which must be taken into consideration is that variously referred to as "cross-fire," "transverse leakage," "weather-

cross," etc., and it may well be taken into account here, as its effects upon the circuit efficiency of open aerial lines are of no less importance than is that of leakage conductance to earth.

During damp or rainy weather, when insulators are covered with a heavy film of moisture, and when cross-arms, pins and poles are water-soaked, there is an intermingling of currents between the various wires on a pole line.

On pole lines where there are a number of wires it is usually the case that some of the circuits are being operated with current strengths considerably in excess of that obtaining in other circuits on the same poles, and the tendency is for the stronger currents to leak into the shorter circuits of lower resistance. Also, there are periods in the operation of all circuits when for an instant (constantly recurring) the regular battery is removed from the line. During these brief intervals in the operation of a given circuit it happens that full-current strength is impressed upon adjacent circuits and the tendency is for these currents to leak through the weather-bound supports into the lines temporarily without battery of their own, and thus create cross-fire, or weather-cross between the two neighboring circuits. In those instances where unfavorable weather conditions extend over any considerable length of line, the effects produced seriously interfere with the efficient operation of circuits. In some cases false signals are produced in receiving relays due to their being actuated by transverse leakage currents from neighboring wires.

Cross-fire disturbances are sometimes attributed to induction, but this conception of the difficulty is in error, as the effects produced are more pronounced during the prevalence of wet weather and should not be confused with the effects attributable to electrostatic or electromagnetic induction.

The weather-cross may be regarded more in the nature of a high resistance contact between adjacent conductors.

Due to variations in temperature, to alteration in the value of total leakage conductance, on long aerial lines the conductivity of wires not infrequently changes as much as 10 per cent., sometimes within a few minutes. This makes it difficult to develop working formulæ which accurately disclose the true conditions to be dealt with. Certainly it is not practicable, nor would it be safe to be governed by formulæ (such as that of the *KR* law) which deal with definite and constant quantities.

In the very thorough and comprehensive investigations conducted by Mr. F. F. Fowle, into the problems of telegraph transmission, in which he starts out as a basis with the well-known differential equation covering the full solution of transmission problems of any character:

$$\frac{d^2E}{ds^2}=LC\frac{d^2E}{dt^2}+(Cr+Lg)\frac{dE}{dt}+rgE$$

in which E = line potential.
s = distance from source.
t = time.
r = line resistance.
g = leakage conductance.
C = line capacity.
L = line inductance.

And proceeding upon the theory that for overhead circuits the only practicable basis of determining circuit efficiency is that having to do with strength of received signals, which permits of the elimination of the time element, the equation resolves into

$$\frac{d^2E}{ds^2} = rgE.$$

The general solution of which and the deductions made therefrom led Mr. Fowle to compile the table shown herewith, which gives the maximum permissable length of line which may be operated satisfactorily, either simplex, duplex, or full quadruplex, over a wire of given resistance per mile.

Conductor resistance per mile	Maximum permissable length of line		
	Simplex	Duplex	Quadruplex
2 ohms	597 miles	783 miles	531 miles
3 ohms	510 miles	658 miles	442 miles
4 ohms	450 miles	580 miles	386 miles
6 ohms	376 miles	485 miles	313 miles
8 ohms	331 miles	425 miles	268 miles
10 ohms	299 miles	384 miles	236 miles
15 ohms	248 miles	318 miles	186 miles
20 ohms	217 miles	278 miles	156 miles

In each case an insulation resistance of 0.25 megohm per mile was used in the investigations from which the above figures were determined.

For the simple Morse or simplex circuits a terminal resistance of 300 ohms was employed. Relays having a resistance of 150 ohms, adjusted to operate on 0.060 ampere, and release on 0.045 ampere, were used in the tests.

The figures submitted for duplex operation assume the employment of polar relays having a total resistance of 800 ohms, and an internal battery resistance of 300 ohms. The relay current was 0.030 ampere. The quadruplex figures are based on the employment of 400-ohm polar relays, 800-ohm

neutral relays, and 600-ohm internal battery resistance. The "short end" potential used was 90 volts, and the "long end" 315 volts.

In comparing the values obtained by means of the "leakage" theory, with those which the *KR* law would give, Mr. Fowle points out that in a given case where a No. 9 copper conductor is employed for telegraph transmission, the leakage theory indicates a maximum operative limit of 314 miles, while the *KR* law would indicate a maximum operative limit of 487 miles.

For an iron wire of approximately No. 8 gage, the leakage theory gives an operative limit of 258 miles, while the *KR* law indicates that the limit of satisfactory operation would be 291 miles.

In calculations dealing with circuit efficiency, it should be kept in mind that in addition to the line-conductor properties—resistance, capacity and leakage conductance—the resistance and inductance of the terminal apparatus (including relays and protective devices) must be treated as important factors having a bearing on the properties of the circuit as a whole.

In considering the question of speed (in words per minute) it is elucidative to regard the speed of the receiving apparatus separately from the speed of the line.

While it is true that the design of a satisfactory receiving relay for high-speed work is hedged about with many requirements, it is generally understood that the "speed" of a line of average length, in good physical and electrical condition, is considerably above the operating speed of the usual electromagnetic types of receiver employed. It is probable that in many cases "400-word-per-minute" lines are equipped at the terminals with "100-word-per-minute" apparatus. On the other hand it sometimes happens that the opposite condition prevails.

In order to reconcile these discrepancies, and with the object of developing a "theory" applicable in all cases, several investigators[1] have suggested that the theory of alternating-current transmission can safely be extended to include the case of signaling over aerial lines and through cables.

The application of this theory requires that the relative frequency of dot and dash signaling compared with the frequency of simple dot signaling, be determined. This consists in finding the receiving end impedance of the circuit, including that of the receiving instruments, and considering the value of the impressed e.m.f. at the transmitting end. In practice it is apparent that the impedance of the receiving apparatus has a decided influence upon the amplitude of the received impulses, and constitutes a factor that must be reckoned with.

From an alternating-current standpoint, the receiving end impedance is the true criterion of speed in any signaling circuit; that is, for given limits of sending voltage, and for given sensibility of receiving instrument. Its application to everyday telegraph requirements, however, is not likely to

[1] Dr. Kennelly, Bela-Gati, Hockin, S. R. Beatty and others.

meet with general favor, on account of the calculation involved. It is apparent also that the information obtainable by that method, would be no more exact, nor would it be as susceptible of simple and rapid application, as is the leakage theory, which requires only tabulated data showing requisite received current strengths.

The inductance possessed by a relay or other electromagnetic receiving instrument is largely dependent upon the efficiency of the magnetic circuit of the instrument.

The magnetic circuit of a relay consists of the iron cores of the magnets, the iron "heel" piece or yoke joining the cores, and the movable iron armature mounted in front of the magnets (see Fig. 88). The more perfect the magnetic circuit, the greater will be the inductance of the electrical circuit which includes the windings of the magnets as a portion thereof. Should the movable iron armature be permitted to come into actual contact with the iron cores of the coils, the magnetic circuit will be complete, and the self-induction of the magnets will be a maximum. If on the other hand the armature is so regulated in its forward travel that it is stopped by the "closed contact" adjusting-screw before coming into contact with the pole-faces, the magnetic circuit will not at any time be complete, and as a consequence the self-induction, or inductance of the magnets will be less than if the magnetic circuit were "complete" as above explained.

For telegraphic purposes it is not always necessary that the magnetic circuit of the receiving instrument should be efficient. In other words there are times (for instance, where high-speed work is concerned) when it is of considerable advantage to sacrifice magnetic efficiency. Especially is this true when by doing so the inductance of the instrument may be reduced.

We have before us now the question of "receiving end impedance" as having a bearing upon the speed of signaling. By referring to Chapter 6, under the heading "Electromagnetic Induction," we find that the resistance in ohms combined with the inductance in henries produces the property known as impedance, and by again reviewing that portion of the work, also the section under the heading "Time-constant" it may be learned that the inductance of the coils of the receiving instrument constitutes a very decisive factor in determining the "speed" of the circuit as a whole.

These various considerations suggest that great caution should be exercised in collating the factors involved in "speed" formulæ.

It is manifestly insufficient to consider only the line factors without regard to the speed capabilities of the receiving apparatus. It is quite possible that in the average investigation considerable time and expense might be devoted to making the speed capabilities of the line or of the instrument higher than they need be. Of course, it is good practice to have reliable margins above the requirements in either case, but it is obvious that expense involved in making a line fifty per cent. faster than the available receiving instrument, is

not justifiable. If the conditions are the reverse, excessive expense in making the receiving instrument unnecessarily faster than is the available circuit, is not justified.

RELAY CHARACTERISTICS

In practice it is found that the design and construction of relays as well as the different products of various manufacturers has considerable to do with the speed capabilities of these receiving instruments.

Tests made with five polar relays procured from five different sources, gave the following values:

Winding	Resistance, ohms	Inductance, henries
1,000 turns, single silk-covered, 31-gage wire, each section.	108	1.88
1,000 turns, single silk-covered, 31-gage wire, each section.	108	2.76
1,400 turns, single silk-covered, 32-gage wire, each section.	193	3.039
1,600 turns, single silk-covered, 32-gage wire, each section.	270	3.921
1,400 turns, single silk-covered, 34-gage wire, each section.	300	5.99

The tests were made with 13 milliamperes current, and 20 mils air-gap between armature and pole-faces of magnets.

Applying the formula for determining the time-constant in seconds $\left(\frac{L}{R}\right)$ in the case of each relay here considered, it may be shown that in the order given, the respective values are:

0.017 second,
0.025 second,
0.015 second,
0.015 second,
0.019 second,

from which it would appear that relays Nos. 3 and 4 should operate at greater speeds than the others. Also that relay No. 1 would be next fastest, and then No. 5 and No. 2 respectively. But these figures apply theoretically only, as they divulge simply the functional performance of the magnetic circuit without regard to the operation of the moving element (the armature) of the relay. Actual speed tests made with the particular relays above considered showed that relay No. 1 when operated on 3-m.a. current failed to

record signals intelligibly, operated at a speed of 30 words per minute. When the current strength was raised to 10 m.a. the signals at 30 words per minute were perfect.

Relay No. 2 performed practically the same as No. 1.

Relay No. 3 operated on 3-m.a. current, recorded perfectly; signals transmitted at the rate of 30 words per minute.

Relay No. 4 performed practically the same as No. 3.

Relay No. 5 performed practically the same as Nos. 1 and 2.

The results, therefore, were not what the time-constant considered alone would have foretold, as theoretically the difference in performance between relays 1 and 2 should have been more pronounced.

Of course, in each of the tests, when the current strength in the relay circuit was raised to average operating value, say 25 m.a., the speed possibilities of each relay were very greatly increased. In the case of polar relay No. 3, for instance, having a time-constant of 0.015 second, it is evident that if the armature in its movements forward and backward faithfully followed the current reversals in the magnet coils, it would make 33 1/3 excursions over and back per second, which on the basis of 15 excursions per average word would signify a speed of 133 1/3 words per minute.

The extra time consumed in forming the dash elements of the letters, naturally would curtail the number of current reversals the relay would be called upon to receive in a given length of time, and this would reduce somewhat the number of words per minute transmitted by means of the dot and dash code.

FIGURE OF MERIT

A number of relays having identical values of inductance and resistance when tested for the purpose of ascertaining the least amount of current required to operate them; generally will be found to vary more or less in this respect. The instrument which operates satisfactorily with the least current strength has the lowest figure of merit. If in a given case a relay is found to operate satisfactorily on 0.002 ampere, the figure of merit of that relay is 2 milliamperes.

RELAY ARMATURE SUPENSION

With the current requirements of the receiving relay well understood, there remain as factors susceptible of alteration, and possibly of improvement, the suspension of the armature and the arrangement of the magnetic circuit.

Fleeming Jenkin, in his book on "Electricity and Magnetism," aptly states the case in regard to the relay armature thus:

"The mass of the armature should be so distributed that its moment of inertia may be the smallest that is consistent with the necessary weight of the armature and position of the pivots; any increase in the moment of inertia produces a proportional diminution in the angular velocity with which the tongue will move under a

given force, and the rate at which a relay will work depends upon this angular velocity. If the moment of inertia be doubled, the force remaining the same, the angular velocity acquired in a given time will be halved, but to traverse the same angle; *i.e.*, to traverse the space between one contact and the other, will not require double the time, but only 1.414 times the period required by the lighter armature, because 1.414 equals the square root of 2. The moment of inertia is the sum of the products of the weight of each particle into the square of its distance from the pivot round which the mass rotates: it is therefore not only desirable when rapid motion is to be produced by a weak force, that the weight should be small, but also that it should be near the pivots. No harm is done, however, by putting the pivots far from the points of contact, because we thereby diminish the angle through which the armature has to move between the contacts; so that if we halve the angle and double the moment of inertia, the one change exactly compensates the other."

It is evident, too, that the forward and backward movement of the iron armature has a bearing upon the efficiency of the magnetic circuit, as the relative position of the armature at a given instant with respect to the pole-faces influences the magnetic condition of the cores. The magnetic circuit is most efficient when the armature is in contact with the cores,[1] the efficiency diminishing rapidly according to the distance to which the armature is removed from the cores. The greater the mass of iron in the cores, the greater the weight of the armature and the slower it moves, the greater will be the influence tending to reduce the speed of signaling.

The length of gap through which the armature tongue is required to travel should be made as short as practicable, as the less the distance through which the armature moves, the more rapidly the signals may be made to succeed each other in forming letters and words.

REDUCING THE TIME-CONSTANT OF RECEIVING RELAYS

With a given instrument there are several ways of reducing the inductance without altering the construction of the magnets and without increasing the ohmic resistance of the windings. The iron heel-piece may be replaced with a brass heel-piece, thus interrupting the continuous magnetic circuit. The individual windings of the coils of the magnets may be connected in multiple instead of in series and thereby effect a reduction of the total self-induction of the instrument.

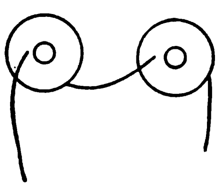
By altering the length or the diameter; or both, of the iron cores, the magnetic circuit may be shortened or lengthened. The shorter the core employed and the less its diameter, the less will be the self-induction in the windings surrounding the cores.[2] It is plain that the period $\frac{L}{R}$ may be reduced in duration,

[1] It should be remembered that efficiency of the magnetic circuit is not necessarily an advantage in relay signaling.

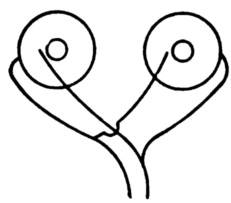
[2] Practically, there are limits to which the reduction in dimension of core may be carried. See Chapter VI, under the head "Electromagnetism and Electromagnets."

by increasing the resistance *R* or by decreasing the inductance *L* of a given relay, and as there are plainly evident objections to increasing the resistance the object should be to do all possible toward reducing the inductance of the relay. How well this has been accomplished in certain types of receiving relay is evidenced by the fact that speeds as high as 400 words per minute have been attained in practice.

Placing the windings of the individual coils in multiple results in a reduction of the effective ampere-turns of the relay. Suppose for instance that the two coils of a relay are connected in series, each coil having 1,000 turns of wire, and that the current in the circuit which includes the windings of the relay has a strength of 50 milliamperes, it is evident that each coil will have 50 ampere-turns. If now the coils are connected in multiple, a joint-circuit will be formed through the two coils, with the result that the 50-m.a. current will divide equally giving 25 m.a. in each coil,[1] or the total ampere-turns for both coils will be 50 instead of 100 as is the case where the two coils are connected in series. It is evident also that the counter-e.m.f. due to self-induction is, in the multiple arrangement, considerably less than with both coils connected in series.



Magnet windings connected in series.



Magnet windings connected in multiple.

FIG. 183.

Figure 183 shows on the left an end view of a pair of coils having their windings connected in series and on the right an end view of a pair of coils with their windings connected in multiple.

SHUNTED CONDENSER METHOD

The effect of self-induction in a relay may be neutralized or "balanced" by means of the arrangement depicted in Fig. 184, where *R* represents the winding of a receiving relay, *NIR* a non-inductive resistance having a total range about equal to the resistance of the line, or the rest of the circuit, and *C* an adjustable condenser. When the key is closed the condenser is given a charge as a result of the potential difference across the resistance coil *NIR* (knowing the value of the e.m.f. applied to the line, and the resistance

[1] This is true only where changing the series circuit into a joint path does not appreciably increase the current value in the circuit.

of the whole circuit, the difference of potential at this point may be calculated by the fall of potential method) placed in shunt with the condenser. It is required that the capacity of the adjustable condenser and the resistance *NIR* be so adjusted that when the key is opened the discharge from the condenser will be equal to that from the coils of the relay *R*. If the resistance *NIR* is made approximately equal to that of the rest of the circuit, the proper

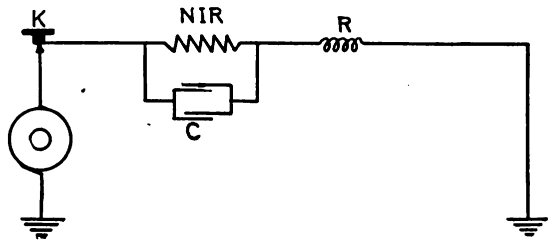


FIG. 184.—Shunted condenser method of balancing the self induction of a receiving relay.

condenser adjustment may be obtained by working the circuit at maximum speed, and then altering the capacity of the condenser until the received signals are at their best.

Where high-speed automatic transmission is in use in connection with tape-marking receivers or high-speed electromagnetic tape-punching receivers, the application of the shunted condenser makes possible considerably higher rates of working, especially where the line so operated is not of unusual length.

CHAPTER XII

SINGLE-LINE REPEATERS

The length of telegraph circuit which may be operated satisfactorily depends upon the prevailing weather conditions which affect the insulation resistance of the line, upon the number of intermediate offices connected into the circuit, upon the method of transmission employed, and upon the speed at which the circuit is to be worked.

From what was stated in the preceding chapter in regard to the properties of telegraph circuits it is apparent that the varying conditions experienced should be met with a variety of circuit arrangements affording flexibility of plant adequate to maintain constant service no matter what the conditions or the service requirements may be.

The difficulties arising from lowered line insulation may necessitate shortening the sections of line operated direct, at least until weather conditions are more favorable; or if the low insulation obtaining is due to other causes, until normal insulation has been restored.

The number of offices connected into an individual circuit; in most cases depends upon traffic and service requirements; but, if from the electrical standpoint the number of offices is excessive and the line long, it is found that during wet weather the relays connected in the circuit at offices near the middle of the line (or where battery is applied to the line at one end only, the relays remote from the battery) operate on greatly reduced variations in current strength when keys are opened and closed in the act of signaling.

The bearing which methods of transmission and signaling speeds have upon the length of circuit which may be operated satisfactorily relates to receiving-end current values, which in turn are dependent upon the resistance, leakage, capacity, etc., of the line wire. As these factors have values practically directly proportional to the length of the line, it is obvious that, as previously stated, there are critical lengths of line which may be operated direct where a given circuit efficiency is to be maintained.

It would be possible to operate a continuous circuit across the American continent (3,500 miles), but the signals would have to be transmitted so slowly that the circuit would be highly inefficient from a telegraphic standpoint, and impossible commercially.

If the 3,500-mile line were divided into sections of approximately 500 miles each, then by means of automatic repeaters located at the junctions of the various sections, the two terminal offices located 3,500 miles apart

can communicate directly, just as if the circuit joining the two offices were continuous and had battery applied at the terminals only.

In this case, however, the speed at which the entire circuit may be operated will be that of the slowest section less the loss in repeaters. It is obvious that the slowest 500-mile section will have a circuit efficiency or signaling speed much greater than that of the entire line operated as one 3,500-mile section.[1]

With adequate supervision and proper maintenance of repeater equipment, a given line 800 miles long and having a speed of 30 words per minute will have its speed possibilities increased fourfold by the introduction of a repeater midway between the terminal stations, thus making two 400-mile sections having speeds of 120 words per minute.

Were the 800-mile line divided into four 200-mile sections, theoretically the speed of the circuit would be 2^2 times 120, or 480 words per minute.

As elsewhere explained, the presence of aerial or underground cable in a telegraph circuit gives to that section of the conductor carried in the cable a higher KR than that possessed by the sections carried on pole lines and separated from other wires by an air space of 12 in. or thereabouts. As the speed of the whole circuit is that of the slowest section, it follows that the speed of the cabled sections constitutes the speed of the circuit.

A simple illustration of the principle of the repeater is shown in Fig. 81, where the signals received by the main-line relay R are repeated into the "local" or sounder circuit, due to the action of the relay armature lever closing and opening the sounder circuit in response to the opening and closing of the main-line circuit through the key K.

Figure 185 shows three stations A, B, and C. Manipulating the key K at A operates the relays at A and at B, and it may be noted that there is a complete electrical circuit from the ground at A, throuth the battery, key and relay at A, then over the line wire, through the relay at B and thence to ground at that point. The operation of the relay at B in response to the manipulations of the key at A causes the armature tongue of the relay at B to close and open the second circuit or section of the line and the armature of the relay at C is caused to move in unison with the armatures of the

[1] Calculation will show that a line 3,500 miles in length made up of wire having a resistance of 4 1/2 ohms per mile will have a line resistance of 15,750 ohms. If the average insulation resistance of the line is 3.9 megohms per mile, with the line open at the distant end the total leak path to earth will have a resistance of 1,114 1/3 ohms. The joint-resistance of the conductor to the distant ground, combined with the various leak paths to ground distributed along the line, will be 1,040 ohms. Therefore, with battery applied at one end of the line only, an e.m.f., of 1,417.5 volts would be required, with a sending current of 1,362 milliamperes to maintain a received current of 90 milliamperes at the distant end of the circuit—1,272 milliamperes having leaked away to earth due to imperfect line insulation.

As explained elsewhere in this work it is inadvisable to employ voltages in excess of 400 in the operation of telegraph lines.

relays at *A* and *B*. Thus the 200-mile line is divided into two 100-mile sections, and the speed possibilities of the whole circuit correspondingly increased.

With the simple arrangement shown in Fig. 185, while station *C* at the end of the second section will receive the signals transmitted by station *A* at the beginning of the first section, it is apparent that station *C* is unable to transmit signals to either station *B* or station *A*, owing to the fact that manipulation of the key at *C* has no effect upon the relay at *B*.

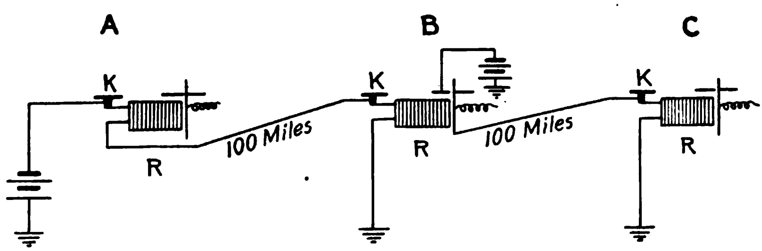


FIG. 185.

In order to maintain operation in either direction, it is essential that station *B* be equipped with a combination of instruments which may be controlled by the key at *C*. So that *C* may send to *A*, *B* should have a set of automatic repeaters, consisting of two relays and two transmitters. This arrangement is called a full set of repeaters. The conditions desired might be represented as in Fig. 186. A signal from the east must operate the

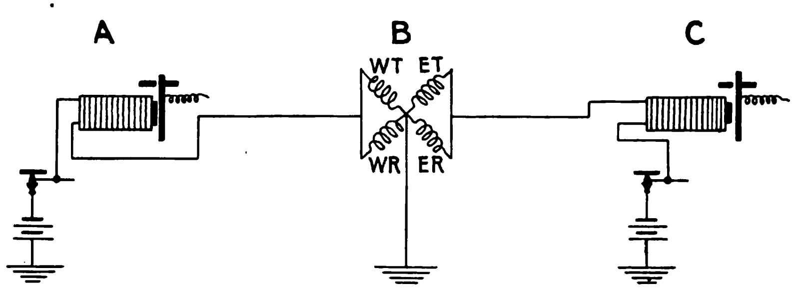


FIG. 186.

east relay and west transmitter, but must not operate the west relay or the east transmitter and, *vice versa*, a signal from the west must operate the west relay and the east transmitter and must not operate the east relay or west transmitter.

A description of the various methods employed to accomplish this amounts to a description of the principles involved in the design and operation of the different repeaters in use, and in what follows, descriptive of the

various standard types of repeater, the student should direct his attention to the means availed of to hold one side of a repeater-set silent while the other side is operating.

WEINY-PHILLIPS REPEATER

Figure 187 shows the local and main-line wiring of a full set of Weiny-Phillips repeaters, in which *R* and *R'* are the relays and *T* and *T'* the transmitters. The "jacks" *J* represent the switchboard terminals of the relay and transmitter circuit extensions from the repeaters.

The organized apparatus illustrated in Fig. 187 has its wiring so arranged that the local circuits are operated by means of gravity or other primary battery. Fig. 188 shows the same repeater equipment with the connections so arranged that the local circuits are fed from a dynamo source of e.m.f.

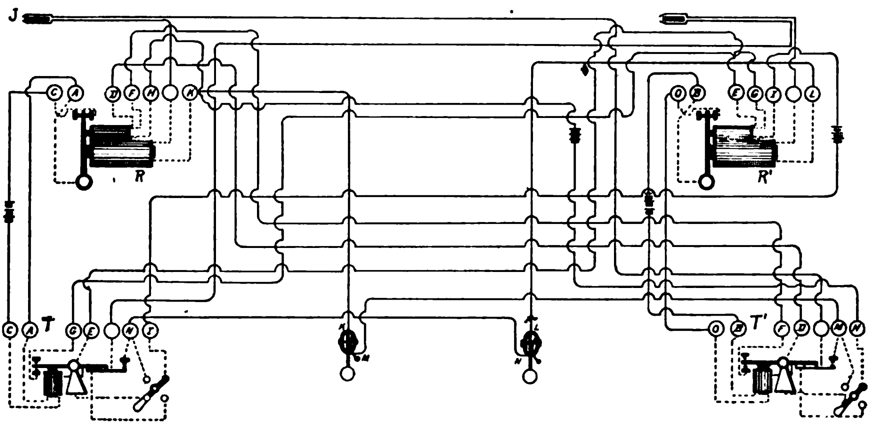


FIG. 187.—Weiny-Phillips single-line repeater. Local and main-line wiring. Transmitters and holding-coils operated from gravity battery.

In Figs. 187 and 188 the shorter magnet mounted above the main-line magnets of the relays is wound differentially. The diagrams show that three wires enter the smaller magnet and the manner in which they are wound around the core is depicted in Figs. 189 and 190.

In Fig. 189, one terminal of the battery is shown grounded while the other terminal is shown connected differentially with two equal windings of the magnet. The current divides at *A*, half going through each coil. It may be observed that the direction of the winding of one coil is opposite to that of the other. Thus, when current flows through the wire *B*, the magnetization of the core due to the action of current in the coil *A–C* is neutralized by the presence of current in the coil *A–D*, and as a result the core is not magnetized at all; so that the retractile spring attached to the armature holds the latter in the "open" position shown in Fig. 189.

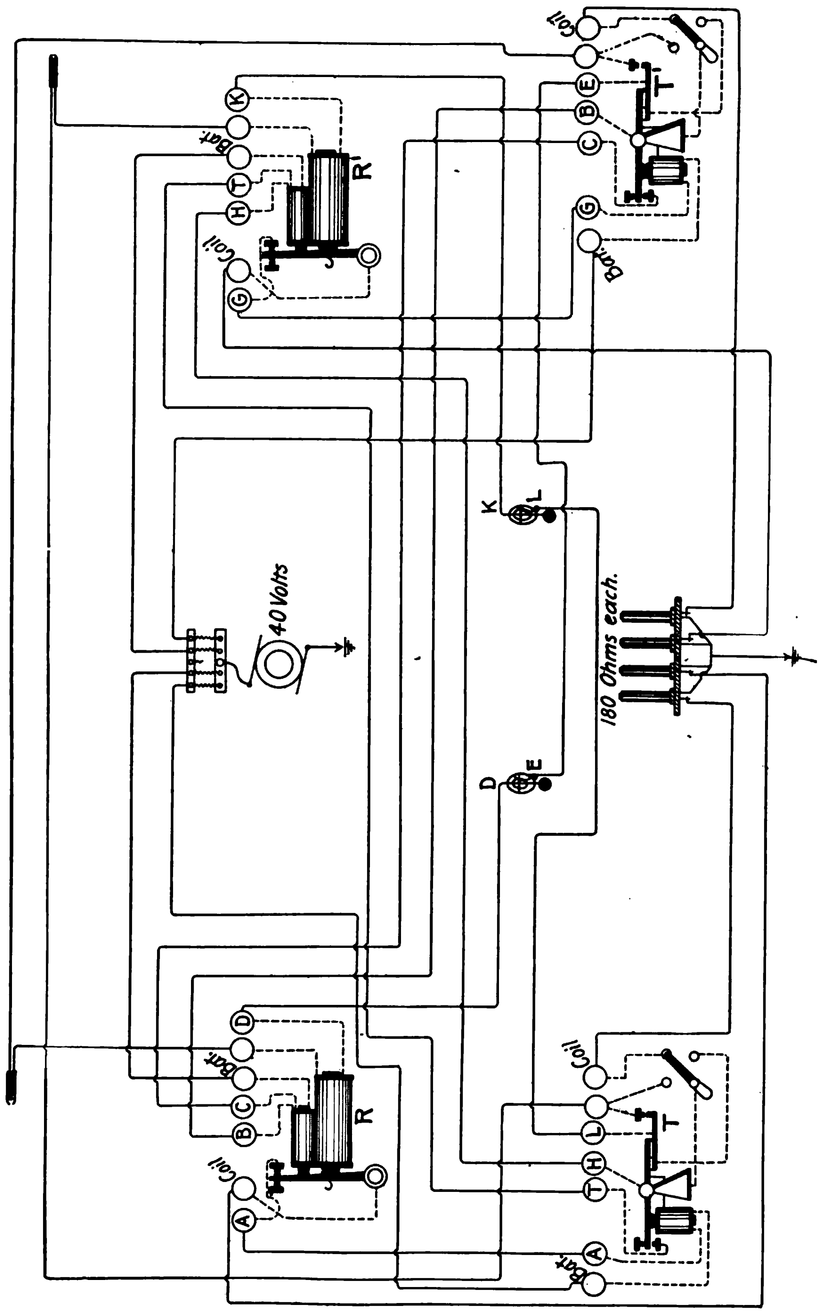


FIG. 188.—Weiny-Phillips single-line repeater. Transmitters and holding-coils operated from a dynamo source of e.m.f.

If, however, while the coil $A-C$ remains closed, the coil $A-D$ is opened, as in Fig. 190, the core will be magnetized due to the presence of current in the coil $A-C$ while no current exists in coil $A-D$, the latter no longer neutralizing the magnetic effect of the former. The armature, therefore, is attracted and held in the "closed" position as shown in Fig. 190.

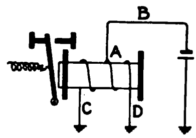


FIG. 189.

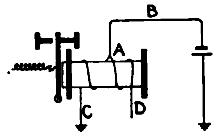


FIG. 190.

FIGS. 189 AND 190.—Differential winding of the holding-coil, Weiny-Phillips repeater.

It is by means of this extra magnet and extra local batteries that the continuity of the line which is repeating into another line is preserved in the Weiny-Phillips repeater.

The "extra" magnet consists of but one coil inclosed in a soft iron shell open at the front or armature end and closed at the opposite end except for a hole at the center through which the end of the iron core projects.

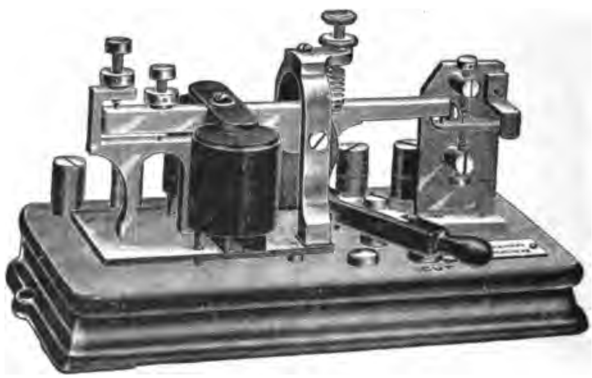


FIG. 191.—Repeater transmitter.

It may be seen (Fig. 187) that the extra magnet and the main-line magnets actuate the same armature, the extra or differential magnet being energized by a local battery and the main-line magnets by current traversing the main-line circuit. When both main-line relays are closed the local connections are such that the local current divides equally between the two windings of the extra magnet, so that the armature is held in the closed position by the action of the main-line current. Should the distant station to the east or to the west open the line, the consequent opening of the local contact-points of the repeater relay, and of the transmitter which it controls,

results in opening one of the windings of the differential magnet. This permits the current in the companion coil to magnetize the core and hold the armature of the relay in the closed position until the main-line circuit is again closed.

Figures 191 and 192 show photographic reproductions of a Weiny-Phillips transmitter and relay respectively.

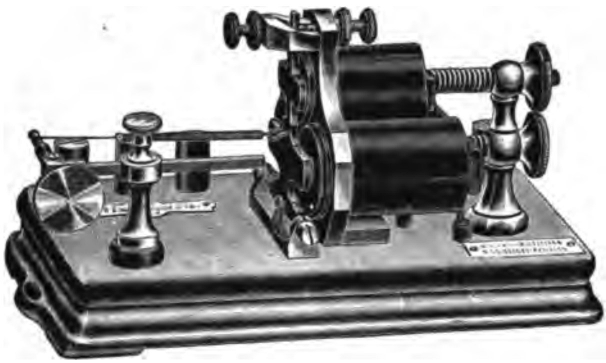


FIG. 192.—Weiny-Phillips repeater relay showing holding-coil mounted above the main-line magnets.

OPERATION OF THE WEINY-PHILLIPS REPEATER

Suppose that in Fig. 187 a line wire extending west of the repeater station is connected to the repeater set through the pin-jack J and that a line extending east is connected to the set through the pin-jack on the right. If the west line is opened (by opening the signaling key at the distant station, or otherwise) the relay R is deprived of current, and as current is flowing through both windings of the differential magnet mounted above the main-line magnets of R, there is no attractive force exerted upon the armature. The result is that the retractile spring attached to the relay armature pulls the latter away from the "closed" contact point, thus opening the battery circuit through the coils of transmitter T. This in turn allows the actuating spring attached to the armature of T to open one of the circuits of the differential magnet mounted above the main-line coils of relay R', thus holding

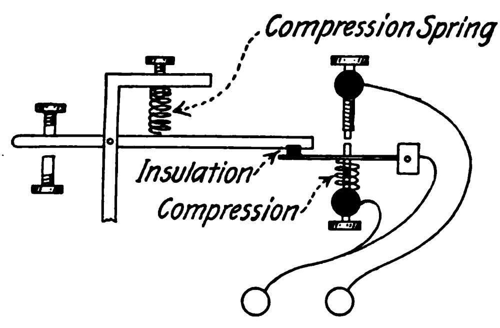


FIG. 193.—Enlarged view of the main line contacts of a repeater transmitter.

the armature tongue of that relay in the closed position, when a moment later the circuit extending to the east is opened at *N*. If the circuits are

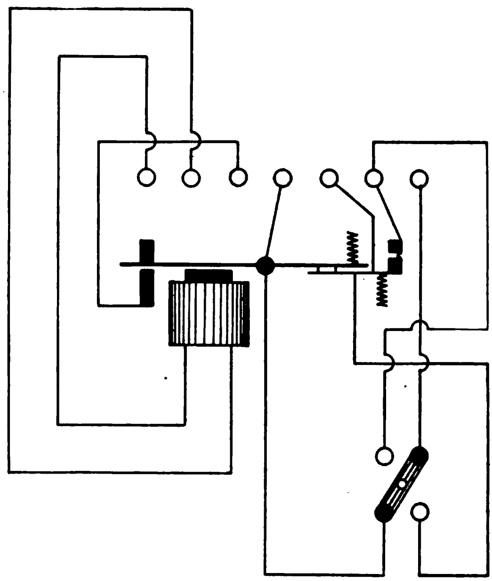


FIG. 194.—Local and main-line connections of a repeater transmitter.

now traced it will be seen that the local circuit through the magnets of transmitter *T′* is prevented from opening, therefore the continuity of the circuit extending west is preserved, and as both windings of the differential magnet of relay *R* are energized, the armature of the latter is withdrawn from the closed contact point as long as the western circuit is held open. As soon, however, as the distant western station closes his signaling key, relay *R* will be energized, thus attracting its armature, which in turn closes the battery circuit through transmitter *T*, and the signal is repeated into the east line as a consequence of the altered position of the armature of transmitter *T*.

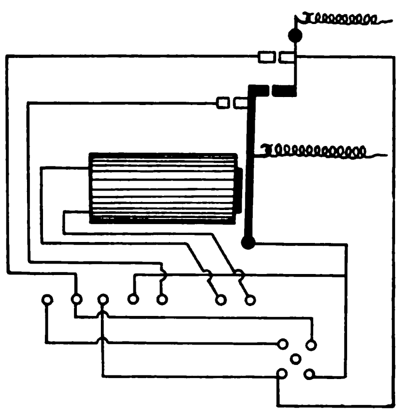


FIG. 195.—New form of repeater transmitter having a vertical lever in place of the horizontal lever shown in Figs. 191 and 194.

Figure 193 shows an enlarged view of the main-line contacts of the transmitter.

Figure 194 shows the connections of a standard pattern of Weiny-

Phillips transmitter with the fulcrums of the levers and the lever actuating springs in their proper relations.

Figure 195 is a diagrammatic view of a recently introduced form of Weiny-Phillips transmitter, having vertical or upright levers in place of the horizontal levers shown in the other figures.

THE ATKINSON REPEATER

In the Atkinson repeater the method availed of to hold the transmitter main-line contacts closed is to employ the lever of a repeating sounder to form a shunt path around the contact points of the relay, when the main-line circuit through the relay coils is opened. This prevents the local circuit, including the magnet windings of the transmitter, from opening.

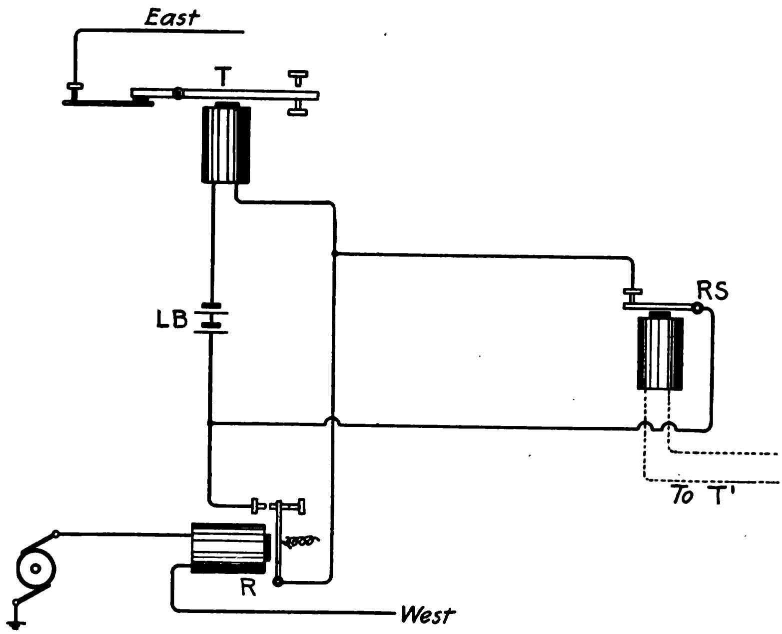


FIG. 196.—Continuity-preserving circuits of the Atkinson repeater.

Figure 196 shows a portion of the Atkinson repeater wiring sufficient to illustrate the theory of the "holding" arrangement. It will be seen that the repeating sounder *RS* is, in operation, controlled by the operation of the circuit extending to transmitter T' in the other half of the set (transmitter T' not shown). At the critical moment the contact points, between which the armature of relay *R* plays, are short circuited, due to the opening

of *RS*, and the local battery *LB* continues to energize the magnets of transmitter *T*, thus preserving the continuity of the line east.

Figure 197 shows the complete theoretical wiring of a full set of Atkinson repeaters.

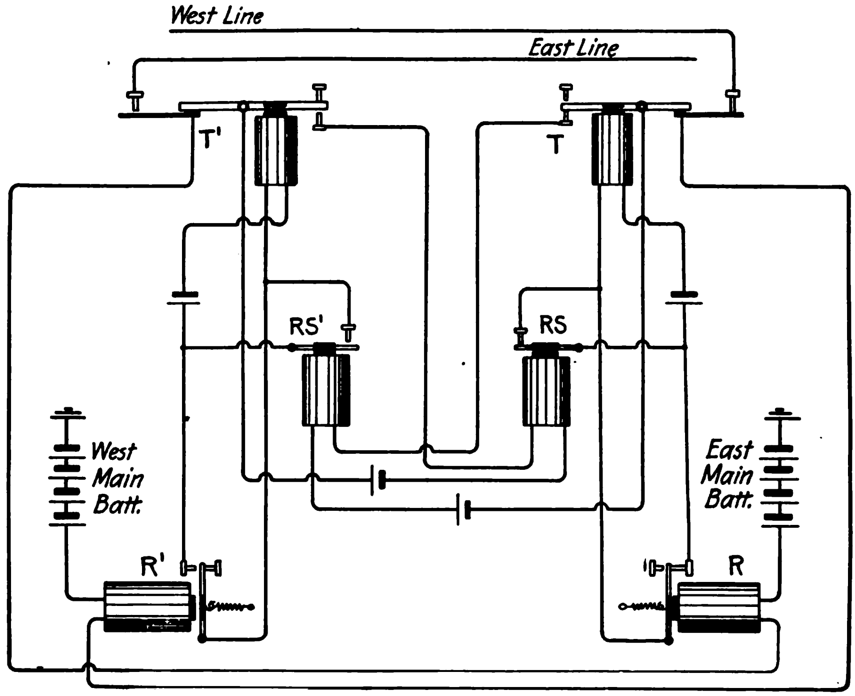


FIG. 197.—The Atkinson single-line repeater. Local and main-line wiring.

OPERATION OF THE ATKINSON REPEATER

As the distant western office opens the signaling key, thereby opening the main-line circuit, relay *R'* "opens" and releases its armature lever which is drawn back by the retractile spring attached to it (as long as the distant eastern office keeps his signaling key closed relay *R* and transmitter *T* will remain closed, provided, of course, that the line west remains closed at the same time) and, when the distant western office closes his key, relay *R'* is energized and its armature immediately closes the local circuit of transmitter *T'*, the result of which is that the main-line eastern battery at the repeater station is placed in contact with the line east through the main-line contact points of transmitter *T'*. It will be observed, however, that the altered position of the lever of transmitter *T'* results in the withdrawal of the armature of *RS*, from the upper contract point, thus removing the

short circuit across the points of relay *R*. Transmitter *T*, however, has not had time to open, as at the instant that *RS*, opened the shunt circuit, relay *R* closed, due to the presence of current in its coils. The passage of signals in the opposite direction through the repeater might be traced in the same manner. In each case it will be found that the opening of the repeating sounder due to the opening of one transmitter results in the opposite transmitter being held closed until the main-line circuit through the relay is again closed.

Figure 198 shows the actual binding-post connections of a full set of Atkinson repeaters.

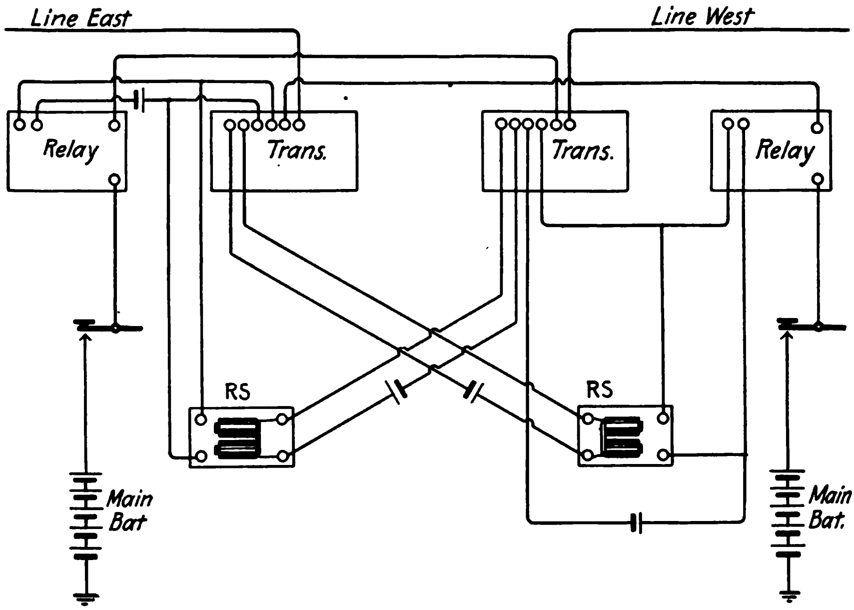


FIG. 198.—Atkinson repeater, binding-post connections.

THE GHEGAN REPEATER

Figure 199 shows the wiring of a full set of Ghegan repeaters arranged for gravity-battery locals. Fig. 200 shows the connections where dynamo currents are employed to operate the transmitters.

OPERATION OF THE GHEGAN REPEATER

Referring to Fig. 199: When the signaling key at the distant western office or the key in the western relay circuit at the repeater station is opened the various armatures assume the positions shown. The armature of relay *R′* first falls back and opens the local circuit of transmitter *T′*, which in turn

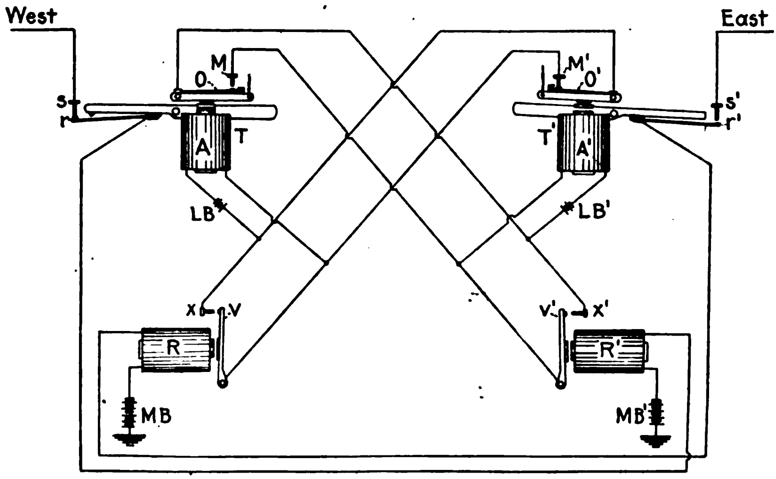


FIG. 199.—Ghegan single-line repeater. Theoretical connections, using gravity battery to operate the transmitters.

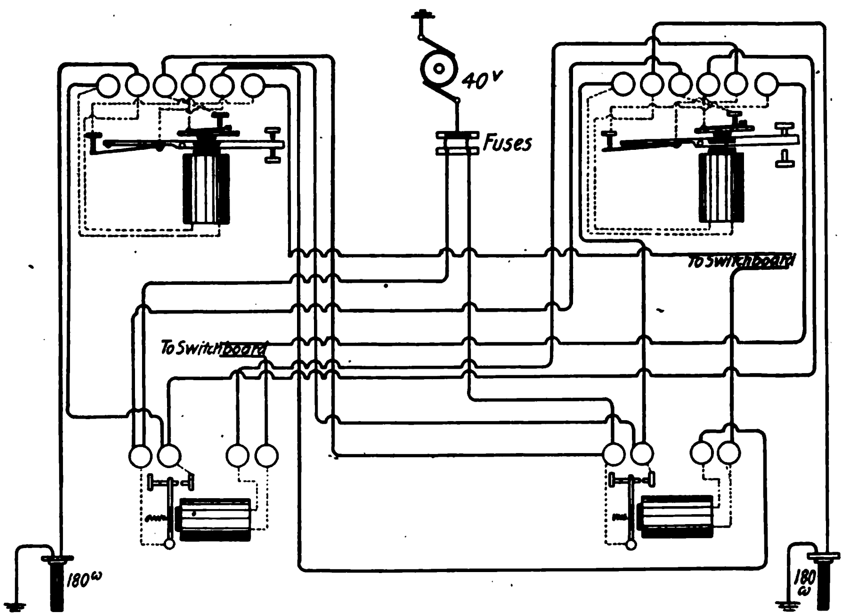


FIG. 200.—Ghegan repeater arranged for dynamo local currents.

opens the eastern circuit at $S'r'$, thereby releasing the armature of relay R. As the armature of the relay is drawn into contact with the back-stop, however, the local circuit of transmitter T is not affected, as, before the eastern circuit was opened at $S'r'$, the shunt circuit around the local contacts of relay R was closed at $M'O'$. Now, when the distant western station closes his key, the armature of relay R' automatically closes the circuit of transmitter T', which in turn first closes the circuit extending east at $S' r'$, and after a sufficient time has elapsed to allow the armature of relay R to reach its closed-contact point, opens the shunt circuit of transmitter T at $M'O'$.

If while the distant western office is sending, the distant eastern office should interrupt or "break," the armature of relay R, will remain on its

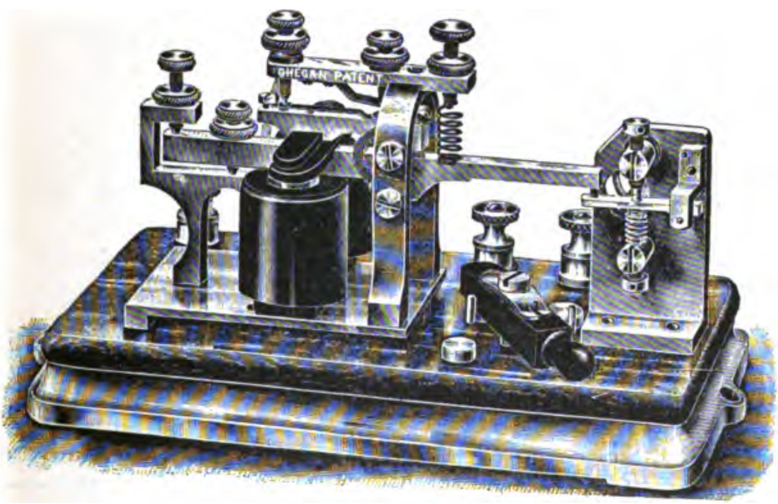


FIG. 201.—Ghegan repeater transmitter.

back contact, thus breaking the local circuit of transmitter T, on the first downward stroke of the superposed armature of transmitter T', and open the western circuit at S, r.

Figure 201 shows a photographic view of the transmitter used in the Ghegan repeater. The superposed armature mounted above the regular armature is clearly shown. The novelty of this repeater is due to the principle that an armature on being drawn toward magnet poles itself becomes magnetic by induction, and the closer the armature approaches the poles of the magnet the stronger the induced magnetism becomes. The employment of this principle insures simultaneous movement of the two armatures, and when the latter are properly adjusted the action of the repeater is quite rapid and certain.

THE NEILSON REPEATER

The unusual feature of the Neilson repeater is that but one local battery is required for the relay and the transmitter of each half of the set. The relays may be ordinary main-line single-contact relays, and the transmitter employed may be either the regulation repeater transmitter or a repeating sounder.

Figure 202 shows the theoretical connections of a Neilson full-set single-line repeater.

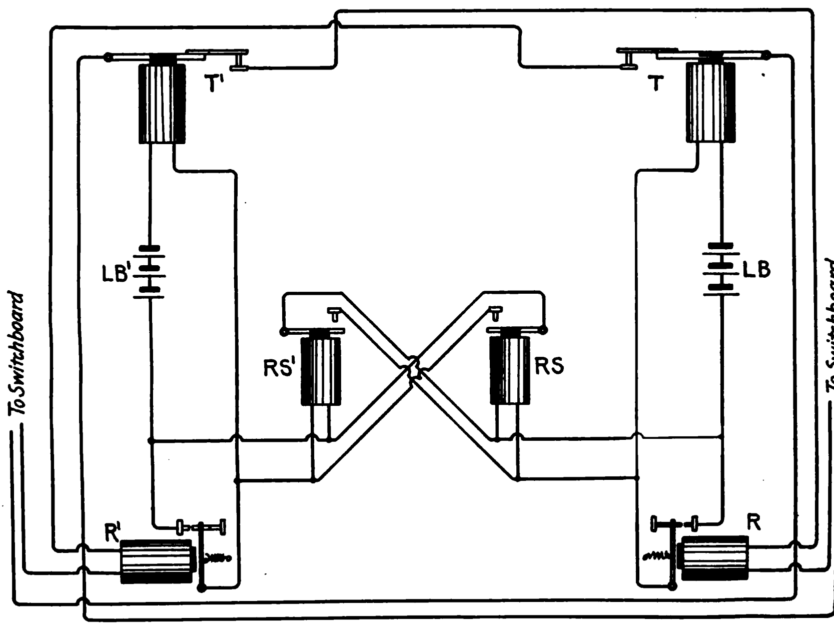


FIG. 202.—Neilson single-line repeater. Theory.

R and *R'* are ordinary 150-ohm main-line relays. *T* and *T'* may be regulation transmitters of from 4 to 10 ohms resistance. *RS* and *RS'* are repeating sounders of 40 ohms resistance.

By referring to Fig. 202 it may be seen that if the main-line relays *R* and *R'* were closed, the armatures of transmitters *T* and *T'* also, would be in the closed position, and the battery circuits of *RS* and *RS'* would be shunted by the armatures of relays *R* and *R'*. It is evident, of course, that with the relay armature withdrawn from its front contact, current from the local battery flows through the magnet coils, both of the transmitter and the repeating sounder; but owing to the great difference in the number of ampere-turns of the windings of the 40-ohm repeating sounder and the 4-ohm transmitter, it is easy to adjust the actuating springs attached to the armature levers of the

two instruments so that when this condition prevails the lever of the transmitter will remain against its back-stop, while the lever of the repeating sounder will be attracted toward its closed contact. This is due to the existing current volume in the circuit being too low to actuate the transmitter, but of sufficient strength to operate the repeating sounder.

By tracing the connections it will be seen that with the armature of *RS* in the position shown in Fig. 202, current flows through the magnet windings of *RS′* and holds its armature closed, and further, that as long as *RS′* remains closed, *RS* must remain open, due to the fact that its windings are now short-circuited. The result is that when *RS′* is closed, transmitter *T* is closed, and when *RS* is closed, transmitter *T′* is closed.

OPERATION OF THE NEILSON REPEATER

With the main-line circuits east and west of the repeating station closed, both relays and both transmitters will be closed, while both of the repeating sounders will be open.

When the distant eastern office opens his main-line key, relay *R* releases its armature, thus opening the short circuit around the coils of *RS*. This places the repeating sounder in series with transmitter *T*, the latter releasing its armature. The opening of *T* automatically opens the circuit extending west, and releases the armature of relay *R′*, thereby removing the short circuit which the armature had maintained across the coils of *RS′*. At the instant, however, that *T* opened, repeating sounder *RS* closed, preventing the closing of *RS′* or the opening of transmitter *T′*, thus the continuity of the line east is preserved.

When the signaling key at the distant eastern office is closed, relay *R* is energized, closing the local circuit, thereby permitting transmitter *T* to close the line extending west from the repeater station. *RS* now being short-circuited by the armature lever of relay *R*, loses its magnetism, and as a result the short circuit around the coils of *RS′* is removed. At the same instant, however (as *R′* is now energized), the other short circuit around *RS′* is closed. Thus it may be seen that *T′* is held closed and *RS′* remains open regardless of whether the line east is open or closed, so that while the distant eastern station is transmitting, transmitter *T′* at the repeater station remains closed.

The operation of "breaking" or of repeating signals from the western circuit to the eastern circuit may readily be traced from the above description.

With the instrument resistance values as herein given it is customary to use four cells of gravity battery in each half of the repeater. Where dynamo currents are availed of, suitable reducing resistances are employed to regulate the current values in the local circuit.

Figure 203 shows the actual binding-post connections of a full set of Neilson repeaters.

The wiring extensions shown leading to the main switchboard usually are brought to pin-jacks, so that one wire from each half of the repeater may be connected through a main-line battery to ground, while the other wire from the same side is connected by means of a cord and wedge, through a spring-jack to the desired main-line wire extending in any direction.[1]

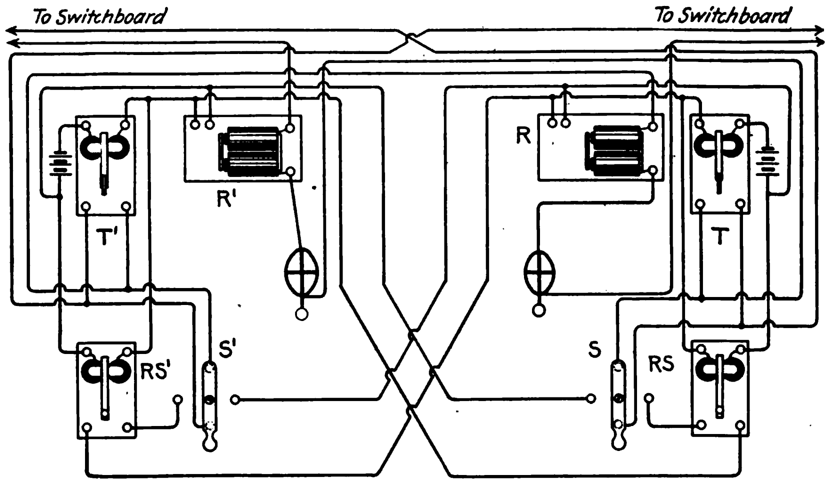


FIG. 203.—Binding-post connections of a Neilson single-line repeater.

THE TOYE REPEATER

In the Toye repeater, no extra magnets or repeating sounders are required. The main-line relay of the wire being repeated into is prevented from releasing its armature, by shifting the main battery from the line to an artificial circuit consisting of a resistance box or rheostat, having a resistance approximately equal to that of the regular line wire to the distant station. The operation of shifting the battery from main to artificial line is performed by the transmitter.

Operation of the Toye Repeater.—By referring to Fig. 204 it may be seen that should the distant eastern office close his main-line key the armature of relay R at the repeating station will be attracted, thereby closing the local battery circuit of transmitter T, placing the lower lip of the transmitter lever points in contact with the line extending to the distant western station. This places the western battery to line west. While the distant eastern station continues to transmit, relay R' and transmitter T' remain closed. The manner in which the silence of these two instruments is maintained con-

[1] It will be shown in Chapter XVIII dealing with multiplex repeaters that full sets of repeaters are usually so provided with table switches, that they may be "split" or divided so that one-half of the set may be used to connect a single line into a duplex set, or into one side of a quadruplex set, at a repeater station.

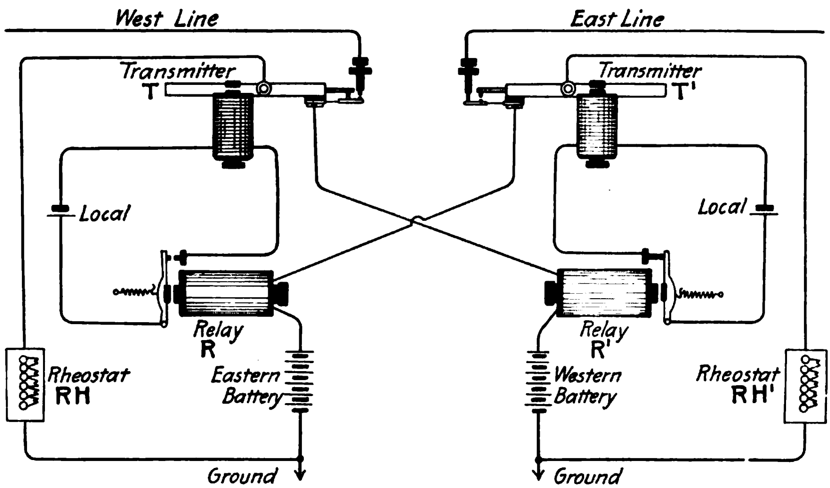


FIG. 204.—Theory of the Toye single-line repeater.

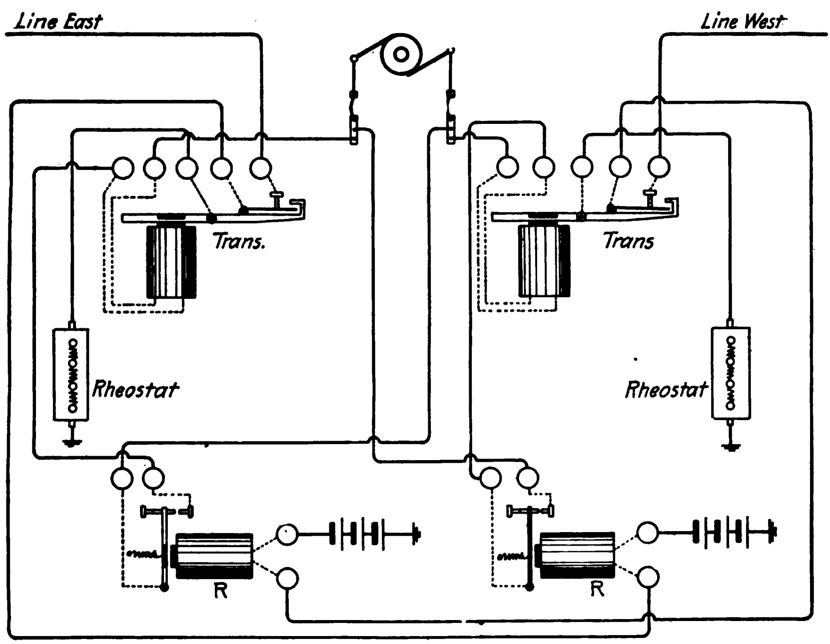


FIG. 205.—Binding-post connections of the Toye repeater.

stitutes the unusual feature of the Toye repeater. It is evident that as long as relay R' remains closed, transmitter T' will remain closed, thus preserving the continuity of the line east while signals are being transmitted from the east to the west through the repeaters.

As transmitter T applies and removes the western battery to and from the west line in response to the operation of relay R, relay R' is prevented from opening due to the fact that the western battery when not in contact with the line west is given a path to earth through the rheostat RH by way of the tongue and lip of transmitter T, thus holding relay R' closed until the western station desires to "break" or to begin transmitting to the eastern station. The transmission of signals from the west to the east is accomplished by the reverse process of that above described.

Figure 205 shows the actual binding-post connections of a full set of Toye repeaters.

In the operation of the Toye repeater it will be seen that the main-line batteries are constantly in use, being at all times applied either to the main lines or to the artificial lines. This means excessive consumption of current, and constitutes an undesirable feature of this type of repeater. It is evident also, that as a particular set of repeaters is applied to lines of different lengths (having different resistance values) the adjustment of the artificial-line resistance must be varied to equal that of the line or lines connected through the repeaters, in order to have equal magnetic pull on the armatures of the relays whether the relay is in circuit with the artificial line or the main line. Naturally it is essential to have regular action of the relay if satisfactory repeating is to be accomplished.

THE MILLIKEN REPEATER

The development of practical telegraph repeaters began in the United States about the year 1855. During the ensuing 10 years satisfactory repeaters were brought out by several well-known workers, among whom might be mentioned J. J. Speed, Jr., Farmer and Woodman, James J. Clark, George B. Hicks, and George F. Milliken. The name of the latter has not been mentioned last as an indication that he followed the others in the development of telegraph repeaters; for in reality he was one of the very first to achieve success in this line, but because his product has survived longer than that of any of the others.

In the Milliken repeater the transmitter armature lever is held in the closed position mechanically through the agency of an extra magnet, the armature of which (when withdrawn by its retractile spring) is in mechanical contact with, and holds the armature of the relay in the closed position during the periods when there is no magnetism in the cores of the relay. The armature lever of the extra magnet is equipped with a retractile spring

which may be given a greater tension than that of the spring attached to the lever of the relay proper (see Fig. 206), which provides that the latter cannot fall back and open the transmitter circuit except at the instant that the stronger extra magnet is attracting its armature toward its closed contact. Obviously while the lever of the extra magnet is in the closed position, the lever of the relay is free to move backward and forward in response to line signals, but while the lever of the extra magnet is withdrawn into contact with its back-stop, the relay lever cannot move, regardless of what takes place in the circuit of which the windings of the relay form a part.

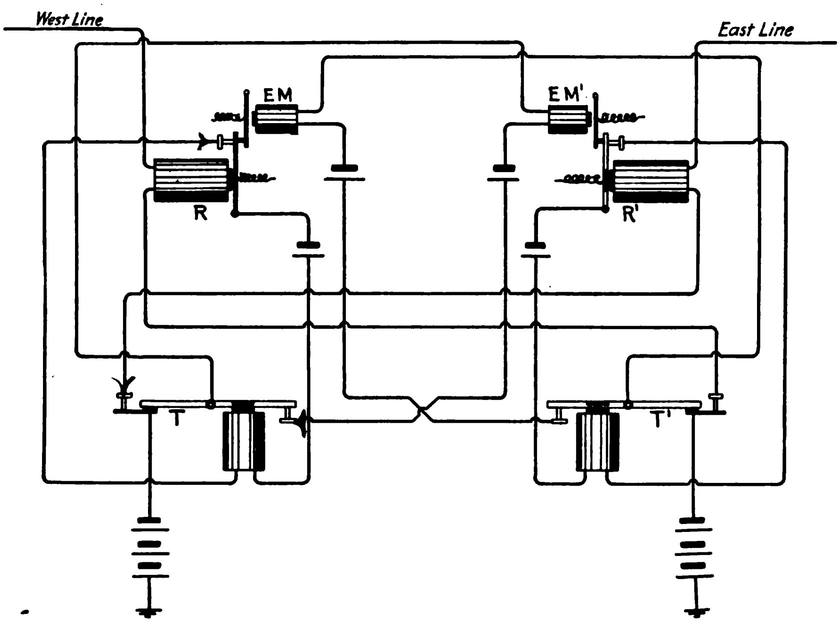


FIG. 206.—Theory of the Milliken single-line repeater.

Operation of the Milliken Repeater.—Referring to Fig. 206: when the distant western office opens his main-line key, relay *R* loses its magnetism, and, owing to the fact that the extra magnet is energized, the armature of relay *R* will fall back and open the local circuit of transmitter *T*, thus removing the main line battery from the line east. When the armature of transmitter *T* is released, it automatically opens the extra local circuit through the winding of EM^1 which results in the armature of R^1 being held closed preventing transmitter T^1 from opening the line west. Thus the continuity of the circuit is preserved. When the distant western office closes his key, relay *R* is energized, resulting in the closing of the local circuit of transmitter *T*, placing the main battery to line east through relay R^1, and

so holding transmitter T^1 closed at the instant that the armature of EM^1 is attracted due to the closing of T.

By noting what takes place in each circuit during the transmission of signals in either direction through the repeater and during the operation of breaking, the action of the repeater under any possible condition may easily be traced.

Figure 207 shows the actual binding post connections of a full set of Milliken repeaters.

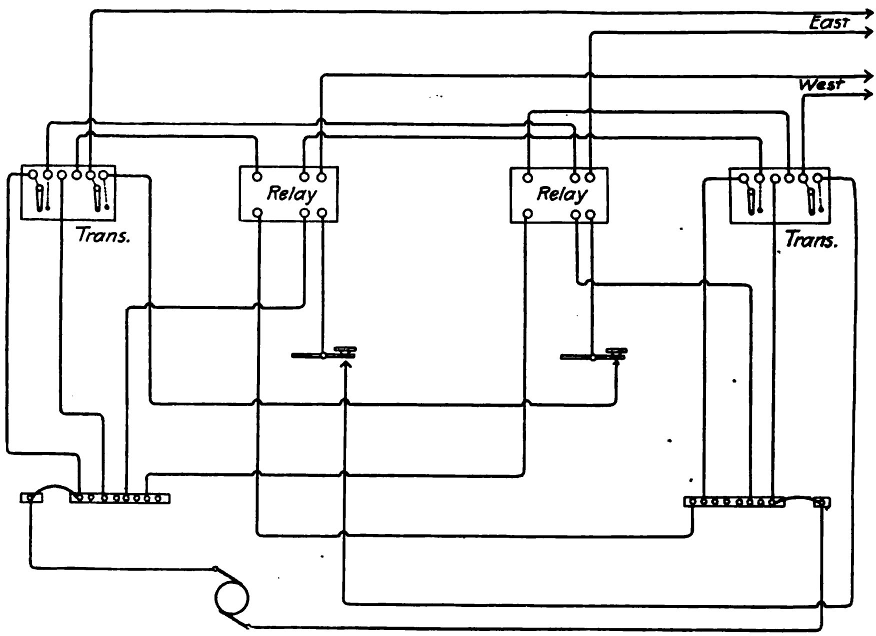


FIG. 207.—Binding-post connections of the Milliken repeater.

THE HORTON REPEATER

As in the case of all other repeaters, the distinguishing feature of the Horton repeater is the method employed to preserve the continuity of the sending main-line circuit while repeating into a separate main-line circuit extending in another direction.

Figure 208 shows the wiring of a full set of Horton repeaters. It may be observed that the wiring of the transmitters, relays, and extra magnets is similar to that of the Milliken repeater, but the way in which the relay tongue is held closed at the critical moment is different from the retractile spring arrangement which is a feature of the Milliken. By referring to Fig. 208 it will be seen that the wood base of the Horton relay is higher at one end than at the other. Due to the force of gravity the armature of the

relay has a natural tendency to fall forward and into contact with the front-stop when the cores of the extra magnet lose their magnetism due to the opening of the extra-local transmitter circuit. It is at once apparent that the relay armature will remain in contact with its front-stop regardless of whether or not there is current in the main-line winding of the relay magnets, but only so long as the retracting magnet is not energized. When the retracting magnet is energized the armature of the relay will be withdrawn when no current traverses the main line coils of the relay. When, however, both the retracting and the main-line coils are energized, the pull of the main-line coils aided as it is by the force of gravity is sufficient to overcome the weaker retracting force and to hold the armature in contact with

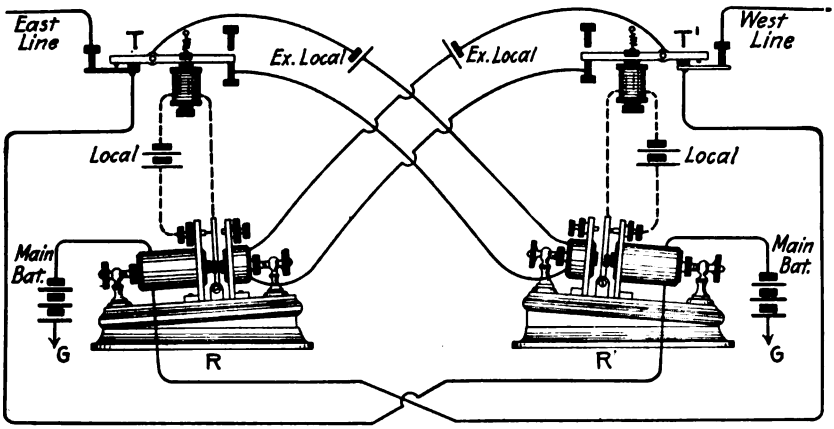


FIG. 208.—The Horton single-line repeater.

the front-stop. The retractile force exerted by the extra magnet may be regulated to suit the requirements in a given case, by means of a threaded adjusting screw which is attached to the heel-piece or yoke of the magnet.

Operation of the Horton Repeater.—Figure 208 shows all circuits closed. When the distant western office opens the main-line key, the current through relay *R* is interrupted, releasing its armature lever which is drawn into contact with the back-stop due to the magnetism of the extra magnet. The local circuit of transmitter *T* is thereby opened, resulting in the tongue of that transmitter moving away from contact with the line east, thereby opening the eastern circuit in response to the open key at the distant western office. At the instant that transmitter *T* opens, the current traversing the main-line coils of relay R^1 is interrupted, and at first sight it might seem that the armature of relay R^1 would instantly be drawn back by the extra magnet thereby opening transmitter T^1 (the very thing that must not happen), but a glance will show that at the instant transmitter *T* opens the circuit through the main-line coils of relay R^1, it also opens the extra local circuit through

the retracting coils of relay R^1, thereby leaving the tongue of that relay in the closed position and unaffected.

A little thoughtful consideration of the repeater circuits in their various relations, with the aid of the foregoing description, will enable the student to trace the operation of the instruments while signals are being passed through in either direction. It is instructive also to observe the action that takes place when the distant eastern office is sending and the office on the line west desires to break. The same action, of course, would take place on the opposite side of the set were the eastern office to break while the western office is sending.

One distinctive advantage that the Horton repeater has over other types, is in the matter of battery economy. One gravity cell in good condition is sufficient to operate each of the extra local circuits, while two cells in good condition are sufficient to operate each transmitter circuit.

THREE-WIRE REPEATER

There are various combinations possible for working three wires into each other, and a description of one such arrangement adaptable to any of the forms of repeater herein described is given herewith.

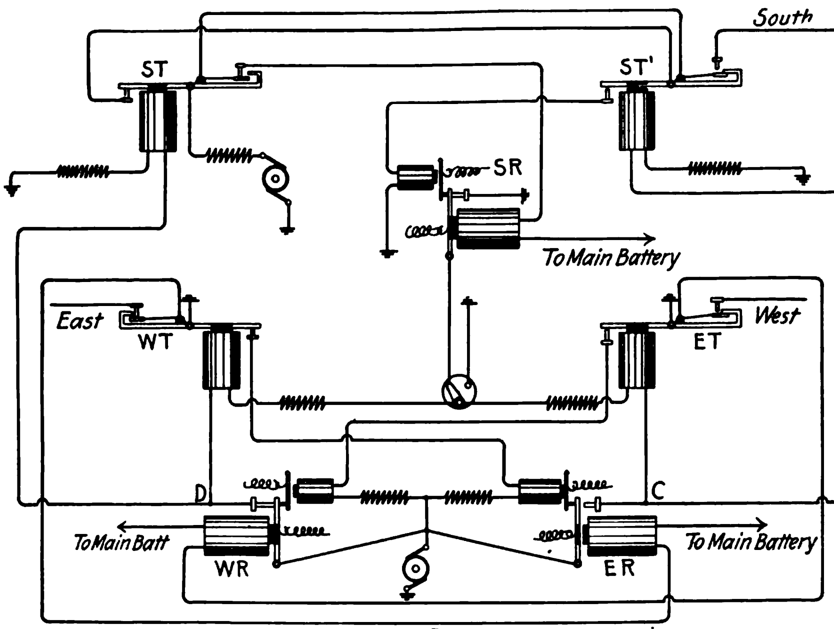


FIG. 209.—Three-way single-line repeater.

Referring to Fig. 209: when all circuits are closed, current from the dynamo flows through the contact points of the eastern relay *ER* to *C* where it splits, part traversing the coils of *ST'* thence passing to ground through a

regulating resistance. Current from the same source traverses the windings of *ET*, and passes thence to the switch, and from there to ground via the contact points of *SR*. The closed-contact points of transmitters *ET* and *ST'* hold the lines extending south and west closed, while the local circuits are held closed through relay *WR* and transmitters *WT* and *ST*.

When an office on the east line opens his key, the levers of the instruments take positions as indicated in Fig. 209. While the east is sending it is necessary that transmitters *ST* and *WT* remain closed in order that the continuity of the transmitting circuit shall be preserved. When the circuit through *ER* opens, it follows that *ET* and *ST'* open at the same time. The back-stop contacts of *ET* open the extra magnet of *WR*, the retractile spring of which holds the contact points of *WR* closed, preserving intact the local circuits,

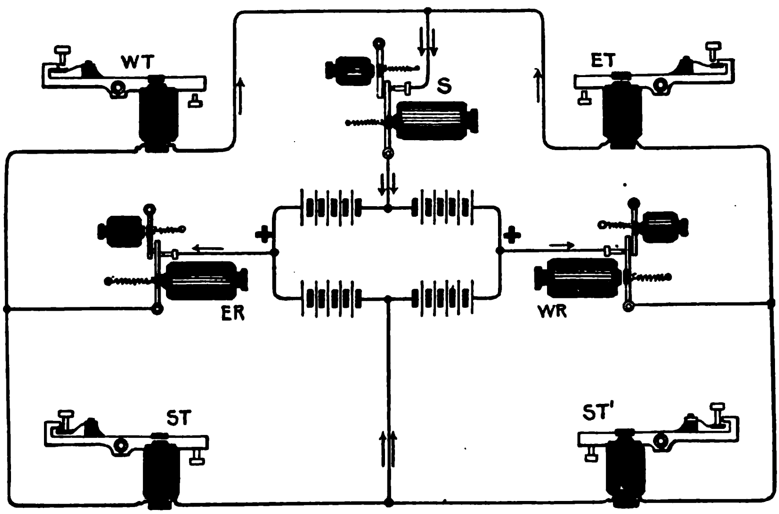


FIG. 210.—Three-way single-line repeater arranged for gravity battery operation of transmitters.

and as a consequence, also, the main line circuits west and south, through transmitters *WT* and *ST*. The back contacts of *ST'*, similarly, open the holding magnet circuit, thus holding the armature of *SR* in the closed position, preserving intact the local circuit through transmitter *WT*.

If while the east is sending into the western and southern lines, the office on the south line should desire to break, the opening of his key interrupts the current in relay *SR*, which automatically removes the ground connection of the local circuits through *ET* and *WT*. The opening of the transmitters is due to the fact that the currents from the two dynamos are of the same polarity, permitting no current flow in the circuit. Whenever, therefore, relay *SR* is being operated, transmitters *ET* and *WT* repeat the signals into the west and east lines.

The arrangement of this three-wire repeater where gravity battery only is available is illustrated in Fig. 210. The diagram shows the local circuits only. The arrows indicate the direction of the currents, and are of material aid to the student in tracing out the various operations that take place, with transmission in any given direction.

SELF-ADJUSTING REPEATERS

It is well known that a repeater of any type requires intelligent supervision and careful adjustment if it is to satisfactorily do the work expected of it.

From what has heretofore been explained in regard to repeater operation it is apparent that the signals transmitted over the line beyond the repeater station are, in a sense, second hand. While the manipulation of the key at the sending station directly controls the operation of the relay at the repeater station, the outgoing signals from the latter office are produced by the transmitter tongue contacts. This makes it imperative that the "breaks" shall be clear, and that the contacts with the line connection be regular and positive; otherwise the repeated signals will not be exact reproductions of the signals received by the relay. Sudden changes in weather conditions along the line must be watched, and the repeater adjustments altered to meet the altered line conditions which result therefrom. Also, in practice, it is found that the individual characteristics in the sending of different operators impose upon repeaters the requirement that they shall operate satisfactorily on different adjustments.

All operators are not capable of sending firm and regular signals by hand. The signals transmitted by a particular operator may reach the repeater station too "light" to permit of satisfactory operation of the local circuits with the ordinary adjustments of releasing springs, magnets, and armature travel. In such cases it is sometimes possible to make the outgoing signals "heavier" by reducing somewhat the tension of retractile springs, by moving magnet cores closer to armatures, or by reducing the "play" of armature tongues between contact points.

In order to insure satisfactory operation of repeaters, it is customary to have repeater attendants in charge of a certain number of sets, whose duties are to supervise the working of circuits operated through repeaters. In many instances it is found advisable to provide an attendant at each repeater station to watch the operation of an individual circuit. Thus, a circuit extending from New York to San Francisco may pass through six repeaters en route, and if the circuit is an important one, or if uninterrupted service and maximum speed is desired, at each of the six repeater stations an attendant (sometimes referred to as a "rider") is assigned to watch the repeater operating in this particular circuit, and to confine his undivided attention to the working of this circuit only.

In view of the foregoing it is no wonder that many attempts have been made to devise a repeater that will be self-adjusting, or a repeater that will remain permanently adjusted regardless of the varying conditions obtaining in the circuit on either side of the repeater station, whether the changes are due to sudden weather changes or to altered characteristics of transmission following a change of sending operators.

THE D'HUMY SELF-ADJUSTING REPEATER

This repeater is designed to fill a special field where certainty of operation is required at all times, on especially poor lines where operating current

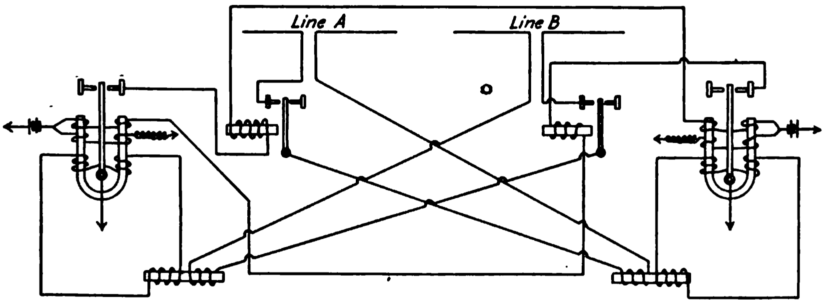


FIG. 211.—d'Humy self-adjusting single-line repeater.

values vary to a degree that makes ordinary single repeater operation exceedingly difficult.

Any change in current value from four or five milliamperes and upward will suffice to operate this type of repeater. The repeater relays consist of

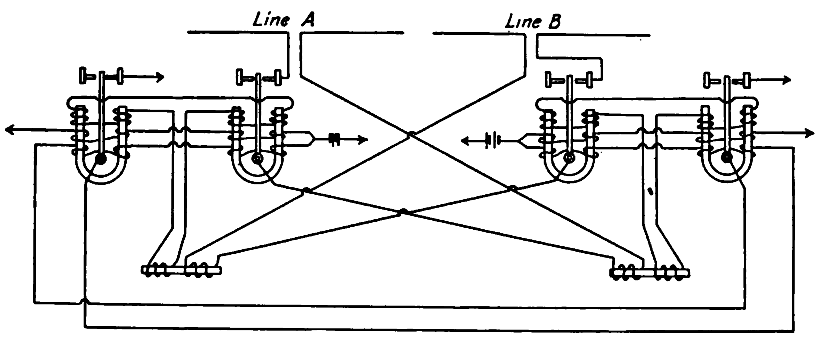


FIG. 212.

"polarized" instruments with three windings, and are operated by currents induced in the secondary windings of an induction-coil. The primary winding of each induction-coil is connected in series with the line wire. One

winding of the polar relay is serially connected with the secondary winding of the induction-coil. The remaining two windings of the polar relay are arranged differentially and serve as a means of "locking" the relays.

Two methods are shown in the accompanying diagrams, Figs. 211 and 212.

In the arrangement shown in Fig. 211 two polarized relays are used with each main line, one relay serving to repeat the signals into the opposite line, while the other is employed to lock the relay operated by the opposite line.

Figure 212 shows a somewhat similar arrangement employing one polar relay and a "pony" relay in connection with each main line wire. The pony relay serves as the means for repeating the signals into the opposite line, while the polar relay serves to actuate the pony relay controlling the operation of the opposite line.

THE CATLIN PERMANENTLY ADJUSTED REPEATER

Another type of repeater designed with the object of securing immunity from the effects of variations in the electrical condition of lines is that invented by Mr. Fred. Catlin, the theory of which is illustrated in Fig. 213.

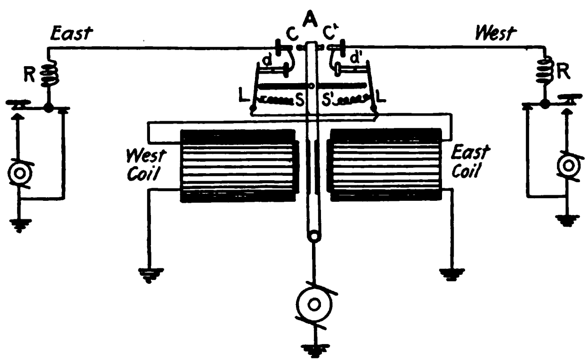


FIG. 213.—Catlin permanently adjusted single-line repeater.

It will be noticed that the armature of the relay stands in the center, midway between the line contacts, which means that when the circuit is idle there is no current in the main line wires. At the distant western and distant eastern stations, battery is applied to the line only when the signaling key is closed.

The system, therefore, will be recognized as similar to the "open circuit" arrangement, previously described in connection with single Morse lines.

At the repeater station, the relay employed is a form of polarized instrument, having a double set of contacts controlled by the movement of the armature.

Referring to Fig. 213: When the eastern office key is in the open position as shown, closing the key at the western office applies battery to the main line at the latter station which furnishes current to actuate the west coil of the relay at the repeater station. As the armature *A* is attracted toward the cores of the west magnet, the contact at *d* is opened and the contact at *C* is closed, thereby opening the ground connection through the east coil of the relay, and applying main-line battery to the line east. Consequently the main-line relay at the eastern station is closed in response to the closed key at the western station. The crossarm represented by the heavy black line is made of ebonite or ivory, and is rigidly attached to the armature, being so adjusted in length that when the gap *C* is closed, the gap *d* is open, due to the fact that the lever *L* (ordinarily held in the closed position by the spring *S*) is pushed away from the closed position by the insulated shaft, or crossarm.

The transmission of a signal from the east to the west would be by the reverse process.

If while the west is sending, the eastern office desires to break, the operator at the latter office closes his key, thereby placing battery to line which causes the armature of the relay at the repeater station to apply battery to the line west, opposing the battery at the western station and instantly interrupting the sender at the latter station.

It is evident that this repeater is practically independent of changes in the volume of line current, and that no alterations in adjustment are necessary when the method of transmission, or the character of the signals is changed.

The method is applicable, however, only in special cases, and where the open-circuit system of signaling may be worked satisfactorily.

NOTES ON REPEATER CONNECTIONS

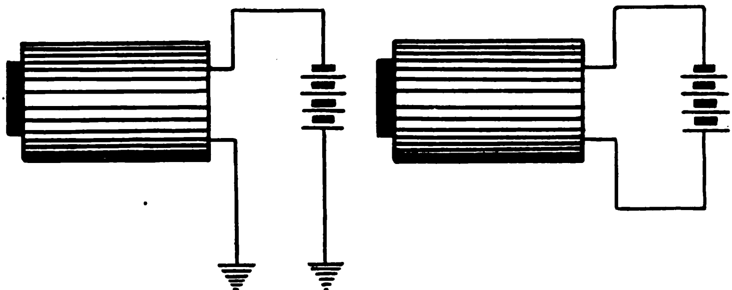
In the various repeater diagrams given, in some instances the local circuits are shown as being supplied with current from primary batteries, in other cases a dynamo is shown as the source of current. Also, in some cases the local batteries are shown connected as indicated in Fig. 214*a*, while in other cases grounded circuits as indicated in Fig. 214*b* are shown.

So far as the operation of the instruments is concerned, it is immaterial whether gravity battery or dynamo current is used, provided the required current strengths are maintained in the various circuits. When battery is used, the internal resistance of the battery as a whole ($n \times r$), in a sense, serves as a protective resistance in case of short circuits. When a dynamo source of current is employed it is necessary to use resistance units in the form of coils of German silver, or other high resistance wire, to protect the dynamos in case of short circuit, and to regulate the volume of current flowing in each circuit.

Local instruments, such as sounders, transmitters, repeating sounders, etc., may be wound to have resistances of 4, 10, 20, 40, or 150 ohms, generally depending upon the current strengths upon which they are to be operated (see Appendix D.). The available e.m.f., for local battery purposes, varies in different installations, and may be 2, 4, 6, 26, 40, 52, or 110 volts.

With a given e.m.f., and a given current requirement, the value of the regulating resistance in a given instance may be ascertained by means of Ohm's law $\left(R=\frac{E}{I}\right)$, always taking into consideration the resistance of the instrument to be operated.

In the interests of economy, in many instances the local commercial 110-volt direct-current is availed of for battery purposes. In which case where



a b

FIG. 214.

150-ohm local instruments (sounders, transmitters, etc.) are used, it is usual to employ resistance units of 1,500 or 2,000 ohms in series with each instrument.

In regard to Figs. 214*a* and 214*b*, it is immaterial which method is availed of so far as current values are involved. Obviously, though, the ground return arrangement (214*a*) makes possible a greatly reduced number of individual connections, and a correspondingly reduced number of conducting wires.

REPEATER ADJUSTMENTS

In the operation of repeaters, it is important to see that all binding-post connections are secure and that circuit contact-points are kept bright and clean. The armatures of transmitters and repeating sounders should be adjusted to have as little play as possible and still permit of clear "breaks" and insure firm and positive "make" contact. This reduces to a minimum the losses due to the mechanical inertia of the comparatively heavy moving parts of the instrument, and makes for more regular performance, and higher speeds.

When a repeater set has been properly adjusted, it does not follow that the circuit made up through it will at all times be satisfactorily operative. That this is so is not necessarily a reflection on the repeater, as in most cases the trouble which develops is primarily due to changes in the weather conditions along the line, thus causing changes in the electrical conditions obtaining in the main-line circuits outside of the repeater. Ordinarily these changes should be met by means of the magnet adjusting screw, moving the magnets closer to, or farther away from the armature as may be necessary. If the retractile springs of relays have a tension sufficient to withdraw the armatures when the current in the magnet windings has fallen to a comparatively low value very little can be gained, but often much harm is done by giving the spring adjustment too much attention.

The main-line contacts if well cleaned, and set close, with all lock-screws tight, should not have to be changed unless excessive sparking occurs. The latter condition may indicate that the points have become dirty, or that an unnecessarily large amount of battery is applied to the circuit.

When the armature of a transmitter is held in the closed position, there should be a space of at least 10 mils (0.010 in.) between the armature and the pole-faces of the magnets. This may be determined by drawing a sheet of ordinary message or writing paper between the armature and the pole faces while the lever is held tightly closed, preferably by magnetizing the cores.

In the working of repeaters a troublesome "kick" occasionally develops, the cause of which is not always easy to locate, and unless the attendant in charge of the repeater has been properly trained and instructed, or has had sufficient experience in the handling of repeaters to enable him to quickly locate the trouble, a repeater set may be thrown out as unworkable when in reality there is nothing wrong except incorrect adjustment.

With any of the standard forms of repeater herein described, when a "kick" develops, the cause which produces it may be run down by the following method. First, open the line key at the repeater station which controls one of the main-line circuits; say that the eastern circuit is selected. Then, with the hand, close and open at intervals the armature of the relay which is open. It should then be noted whether the kick appears when the relay armature makes contact with its front-stop, or when the armature is moved away from that point. If the kick is in evidence when the relay closes, the indications are that the relay in circuit with the opposite line (in this case the west relay) does not act quickly enough to maintain the closed position of the transmitter armature at the instant the holding coil, or repeating sounder "lets go" in response to the closing of the opposite transmitter. In the case of the Weiny-Phillips repeater this means that there is too great an interval of time elapsing between the instant the holding coil of the relay releases the armature, and the instant the main-line coils of the same relay "take hold" of the armature. The cause may be that the tongue

of the transmitter does not close the main-line circuit at an instant coinciding closely enough with that at which current is made to flow differentially through the windings of the holding coil of the relay. This means that the holding coil releases the armature before the main-line coils have become magnetized, and this interval although brief may cause a kick of the armature of the opposite transmitter. If it is found that the transmitter adjustment is correct, the trouble may be due to the main-line coils of the relay being pulled back too far in a direction away from the armature. In either case the remedy is proper adjustment. If the kick is in evidence at the instant that the relay armature is moved away from the front stop the cause will likely be found to be tardy action of the repeating sounder, holding magnet, or other holding device. In which case the trouble (in the case of the Atkinson repeater) may be eliminated by lifting the armature of the repeating sounder a trifle, or by giving the spring a greater tension. If the set in trouble is of the Weiny-Phillips pattern, moving the holding coil closer to the relay armature, will in most cases eliminate the kick which develops when the relay armature is moved away from the closed contact.

Should the kick appear in the other half of the set, its cause may be located by the process the reverse of that just described; that is, by manipulating the armature of the west relay, for the purpose of determining whether the kick appears when the relay armature is moved into contact with, or away from the front-stop.

CHAPTER XIII

DUPLEX TELEGRAPHY

By duplex telegraphy is meant a system which makes possible the transmission of two messages over a single wire at the same time, one in each direction.

THE SINGLE-CURRENT DUPLEX

The more important elements of the single-current duplex are the transmitter, the differential relay, the artificial-line rheostat, and the condenser.

The single-current duplex is sometimes referred to as the Stearns duplex in honor of the inventor, Mr. Joseph B. Stearns.

In single Morse circuits, such as those described in Chapter VII, the armatures of all relays in the circuit, including that at the home station

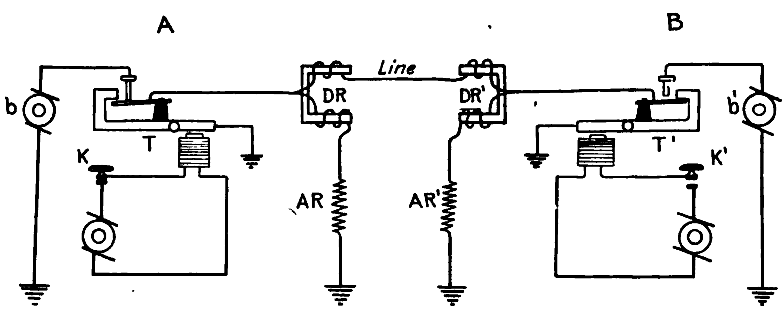


FIG. 215.—Single-current, or Stearns differential duplex.

and that at the distant station, are operated simultaneously when any signaling key connected into the circuit is manipulated.

When it is required to transmit a message in each direction over a line simultaneously, it is evident that the receiving relay at each of the two terminal stations must respond to the manipulations of the signaling key at the distant station, and not to the operation of the key at the home station.

Figure 215 is a diagram of the theoretical connections of the single-current duplex. A line is shown extending between stations A and B. T and T' are the transmitters, DR and DR' the differential relays, AR and AR' the artificial-line rheostats, and b and b' the main-line batteries at A and B

respectively. The function of the transmitter is simply that of a signaling key connected into the main-line circuit in such a manner that when the key is closed battery is appllied to the line, and when the key is opened the line is grounded.

Figure 216 shows a key connected into the main-line circuit direct, to do the work of a transmitter. Here, as in the case of the transmitter shown in Fig. 215, it is apparent that when the key is depressed, battery is applied to the line, and when the key is opened the line is grounded.

In the operation of duplexes—as will be explained more fully later on—it is essential that in the operation of the transmitter or of the key, the shortest possible interval of time shall elapse between the instant battery is removed from the main line, and the instant the ground connection is

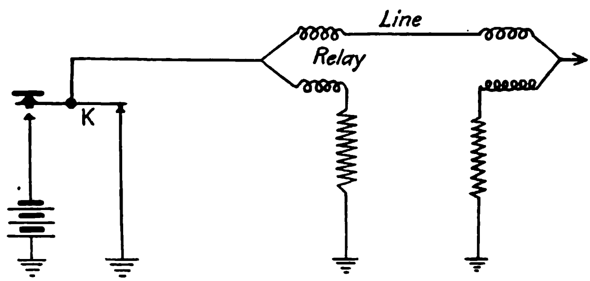


FIG. 216.—Showing an ordinary Morse key taking the place of the transmitter in a single-current duplex.

substituted therefor. Obviously if an ordinary key were used to control the application of battery and removal of ground connection, and *vice versa,* in the act of signaling; the lapse of time between these two contacts would be excessive, due to the comparatively slow movement of the hand in working the key; being more pronounced the wider the gap maintained between the contacts of the key. Also, were the ordinary key used directly in the line circuit, the speed of operation would be considerably curtailed owing to the requirement imposed upon the operator to make equally firm and solid contact between the key-lever and the ground connection as between the lever and the battery contact; a condition that the average operator would find qüite difficult to meet.

The transmitter, therefore, is used for the purpose of insuring instantaneous transfer of the line connection from battery contact to ground contact in response to the operation of the key which controls the operation locally, of the transmitter, regardless of whether the key is operated rapidly or slowly.

By noting the construction of the transmitter shown in connection with the diagram, Fig. 215, it may be seen that the moving element of the instrument may be so adjusted that at the instant the battery is removed, the

ground contact is made, and thus the continuity of the line is preserved, or in other words, the period during which the line is open is reduced to a minimum. This is a requirement of considerable consequence in the operation of multiplex telegraphs.

THE DIFFERENTIAL RELAY

If the reader will review what was stated in Chapter X, page 155, in regard to the differential galvanometer, and in Chapter XII, page 224, dealing with the differentially wound holding magnet of the Weiny-Phillips repeater relay, he will be better prepared to understand the construction of and the operation of the differential relay used in connection with duplex and quadruplex telegraphs.

All that is required is that when currents of equal strength pass through both windings of the differential magnet, the cores shall not become magnetized. It is to be remembered, however, that the amount of magnetism produced in either core is directly dependent upon the strength of current flowing in the winding around the core, and if the magnetic effect produced by one of the coils is to be exactly neutralized by that of the other, it is essential that the current strength in the two coils be equal.

If the current strength in one coil is greater than that in the other coil, naturally the excess current produces a certain amount of magnetism which is not neutralized, and, due to this magnetism, the armature of the relay is attracted.

In an earlier chapter it was explained that the strength of the current flowing in a circuit is dependent upon the value of the applied e.m.f. and upon the ohmic resistance of the circuit. In the case of the differential relay, therefore, it is essential that if the relay is to be truly differential, the current strength in both windings must be identical, and this in turn imposes the requirement that the resistance of each circuit must be identical.

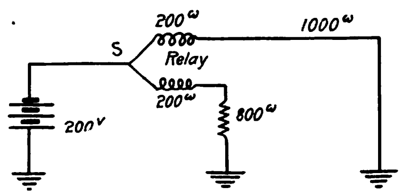


FIG. 217.

Suppose a differential relay having a resistance of 200 ohms in each winding is connected with a source of e.m.f. so that current flows through both coils as indicated in Fig. 217. If it is required that the cores of the relay magnets shall not be magnetized, it is necessary that equal current values obtain in each of the divided paths to ground. The fact that the resistance of each of the relay coils is the same is of little consequence unless the circuits beyond the relay also are of equal resistance.

In Fig. 217, current passes through one coil of the relay and beyond through a line wire having 1,000 ohms resistance, thence to ground. The

other coil of the relay forms a portion of a path to ground through a resistance coil of 800 ohms. It is evident, therefore, that as the current divides at S it has two paths to ground, one having a resistance of 1,000 ohms and the other a resistance of 1,200 ohms, and it is apparent that there will be more current flowing in the circuit having less resistance than in the other. As a consequence, one core of the relay is to a certain extent magnetized due to the extra current in one coil of the relay over that in the other coil.

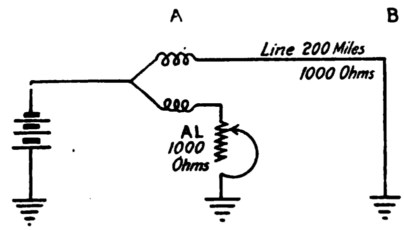


FIG. 218.—Resistance of the artificial line balancing the resistance of the line wire to distant station.

The resistance of main-line wires varies from a few hundred ohms to several thousand ohms and where differential relays are used in duplex operation, in order to insure that equal current values obtain in each coil of the relay when the home battery is applied to the line and the distant end of the line is grounded, it is necessary to have at the home station an adjustable resistance through which the other coil of the relay may be connected to ground.

Obviously if this resistance is adjusted to have a value equal to that of the line wire to the distant station, like current values will exist in both coils of the relay and there will not be any magnetism produced in the cores of the relay.

The adjustable resistance used to equate the resistance of the main-line wire is generally called the artificial line, Fig. 218.

THE ARTIFICIAL LINE

As has been pointed out elsewhere in this work, all line wires possess electrostatic capacity. The quantity of electric charge accumulated upon the surface of the conductor depends upon the superficial area of the conductor, upon the distance intervening between the conductor and the earth (or between the conductor concerned and other conductors in electrical contact with the earth), and upon the nature of the insulating medium intervening between the line wire and the earth. In any line of considerable length, a portion of the current is bound up in the form of static charge.

The first rush of current into the line at the instant the battery is applied thereto, (sometimes referred to as the current of charge) for an instant produces a much greater magnetic effect upon the armature of the home relay, than obtains when the entire line has been fully charged and permanent conditions established in the circuit.

The result of the initial inrush of current, greatly exceeding in volume, as it does, the final current, is that a false signal or "kick" of the relay ar-

mature is produced. The energy of the kick depends upon the electrostatic capacity of the line, being greater where the capacity is high, and less pronounced as the static charge taken on by the line wire is less.

Also, there is to be considered the effect of static discharge which occurs at the instant the line wire is shifted from the battery connection to the ground connection upon opening the key controlling the operation of the transmitter. At this instant the electrostatic charge which has been accumulated upon the surface of the conductor flows back to ground by way of the ground contact of the transmitter, passing through the main-line coil of the differential relay, again producing a kick of the relay armature.

In view of these considerations, therefore, it is necessary if the false signals which are produced at the beginning and the end of each intended signal are to be neutralized or nullified, that the artificial line be made to possess properties identical with those of the main-line wire, *i.e.*, resistance and capacity.

The application of the electric condenser as an adjunct of the artificial line gives to the latter the desired property of electrostatic capacity.

A condenser path to ground via the artificial-line coil of the differential relay results in an initial rush of current through that coil at the instant battery is applied to the line, which, by means of adjustable "timing" resistances in series therewith may be made to exactly equal in strength and duration, the corresponding rush of current which takes place at the same instant through the main-line coil of the relay, thus at the critical moment insuring identical current values in both coils of the relay.

And, further, when the line wire is shifted from battery contact to the ground connection at the moment the key is opened, the discharge from the condenser associated with the artificial line takes place through the relay coil forming a portion of the artificial-line circuit at the same instant that the main line discharges through the relay coil forming a portion of the main-line circuit, thus again at the critical moment insuring equal current values in the two coils.

To understand the import of the above remarks, one must have in mind the positions of the main-line circuit and of the artificial-line circuit through the windings of the respective relay coils, also that the magnet made up by the artificial-line relay coil, and the magnet made up by the main-line relay coil both control the same armature.

When the relay is operated by current from the distant station its operation is due to a surplus of current in the main-line coil over what may be in the artificial-line coil of the relay.

When the signaling keys at each end of the line are closed and like poles of battery are applied at both ends of the line, the desired signal is made by the home battery on the home relay, and is the result of a surplus of current in the artificial-line coil of the relay over what may be in the main-line coil.

When, due to electrostatic charge or discharge of the main line the current in the main-line coil of the relay is augmented above that traversing the artificial-line coil of the relay, a false signal will be produced unless at that instant the current flowing in the artificial-line side of the relay is increased to an equal value. This is what is accomplished by using condensers and retardation resistance coils in connection with the artificial line.

Figure 219 shows the theoretical arrangement of the artificial-line circuits. On the right is shown three adjustable resistance groups used in balancing the "ohmic" resistance of the main-line wire. With the values shown it is possible to avail of resistances ranging from 10 ohms to 11,100 ohms, variable within steps of 10 ohms.

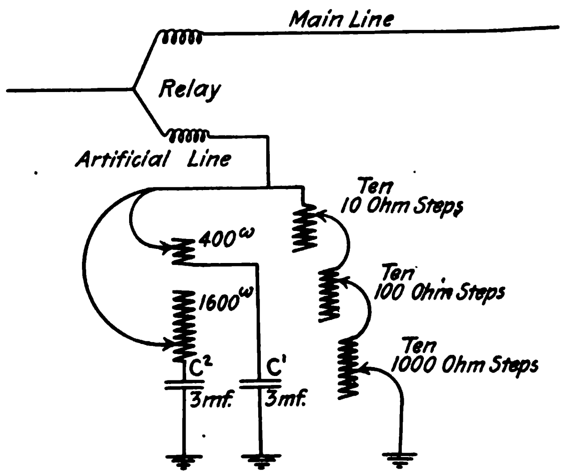


FIG. 219.—Circuits of the artificial line, showing the adjustable resistance on the right and the condensers and condenser timing resistances on the left.

On the left, two adjustable electric condensers C^1 and C^2 are shown, each having a maximum capacity of 3 microfarads. Each condenser has in series with it an adjustable resistance (see Timing the Condenser Discharge).

DOUBLE-CURRENT DUPLEX SYSTEMS

As a result of the development of more efficient and satisfactory duplex systems, the single-current duplex is rarely used in this country, except where it is combined with the polar duplex in forming the differential quadruplex system of telegraphy by means of which two messages are sent in each direction over a single wire, simultaneously.

Further treatment of the single-current duplex will be deferred until it is considered as a component part of the quadruplex.

THE POLAR DUPLEX

The essential elements of the polar duplex are a battery pole-changer, a differentially wound polarized relay, an artificial line rheostat, and an artificial capacity.

THE POLE-CHANGER

The transmitter shown in connection with the single-current duplex, Fig. 215, has connected to one of its contacts the positive pole of a main-line battery and to the other contact a circuit to ground. If to the latter the negative pole of a main-line battery were connected instead of the ground wire, closing the signaling key would send to line a positive impulse, and opening the key would send to line a negative impulse, in which case the transmitter might correctly be regarded as serving as a pole-changer, inasmuch as the polarity of the battery placed in contact with the line wire changes from positive to negative and *vice versa* each time the transmitter tongue is caused to break contact with the positive battery terminal and make contact with the negative battery terminal.

When dynamo currents were introduced in the operation of telegraph lines it was found that the form of transmitter here considered, and which had previously answered the requirements where gravity batteries were universally employed in telegraph work, failed to give satisfactory results owing to the momentary short circuit which exists when the line contact is shifted from the lever to the tongue of the transmitter, and again when the opposite movement takes place, in the act of signaling. In the Stearns duplex the resistance presented to the individual battery used, was, at the instant the transfer of contact took place, made approximately equal to that of the total internal resistance of the battery. When the dynamo with its negligible internal resistance is applied to the operation of the polar duplex, two machines of equal potential and of opposite polarity are separately connected to the contacts between which plays the armature tongue carrying the main-line contact. At the instant, therefore, that the transfer of contact takes place unless there is an appreciable length of air-gap maintained between the opposing battery terminals, there will be established a momentary short circuit between the two dynamos (where two 200-volt machines are employed this amounts to an aggregate potential of 400 volts) which might result in serious damage to the machines. Even where artificial resistances are inserted in series with each machine, excessive sparking occurs when the line contact is shifted from one pole to the other.

The introduction of the double-current duplex called for the substitution of a transmitter in place of the type of instrument used with the single-current duplex, which would meet the changed conditions.

The new form of transmitter, or pole-changer as it has since been called, provides for the maintenance of an air-gap as the main-line contact is shifted from one pole of the battery to the other.

One form of pole-changer employed by one of the commercial telegraph companies, is that known as the walking-beam pattern, see Fig. 220.

Another type of pole-changer extensively employed is that illustrated in

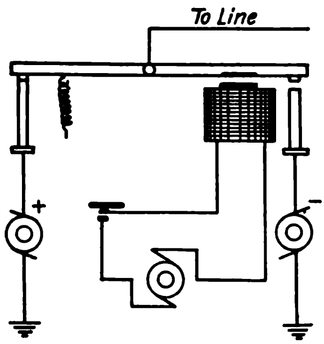


FIG. 220.—Walking-beam pattern of pole-changer.

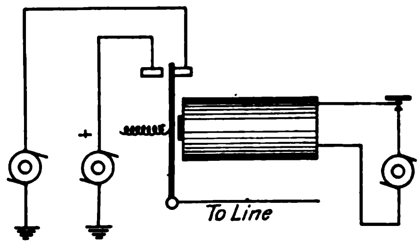


FIG. 221.—Double-contact relay type of pole-changer.

Fig. 221, which will be recognized as a simple double-contact relay form of instrument, a photographic view of which is shown in Fig. 222.

With either of these instruments, it is evident that connection cannot be made between the line and one dynamo until contact has first been broken between the line (the lever) and the other dynamo connection.

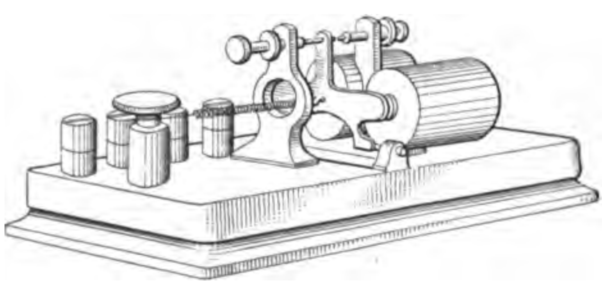


FIG. 222.—Pole-changer.

So far as the polar duplex is concerned, the same necessity does not exist for the employment of a continuity-preserving transmitter as was the case with the single-current duplex, the reason for which will be explained presently.

The combination of the polar duplex with the Stearns duplex, in forming the differential quadruplex, transferred to the latter the alternative of using

on the single-current half of the system a continuity-preserving transmitter, or a pole-changer type of transmitter which at all times maintains a small air-gap between the opposing dynamo terminals. From what has been stated in regard to the possibility of short circuits where the continuity-preserving instrument is used in connection with dynamo machines, it is apparent that the employment of the latter mentioned instrument is not practicable. In practice, therefore, it is customary to use an open-gap transmitter on the single-current side of the quadruplex, similar to that used on the double-current side.

In the operation of the single-current side of the quadruplex, the objections previously mentioned in connection with the employment of the air-gap transmitter in Stearns duplex operation, still exist, as it is evident that there are constantly recurring periods of "insufficient current" while the lever of the transmitter (to which the line conductor is connected) is traveling from one battery contact to the other in the act of signaling.

Inasmuch, however, as the employment of the open-gap transmitter is imperative, it has been necessary to avail of other means of bridging over these periods, and to employ circuit accessories which act to prevent, or at least to minimize the tendency to produce false signals on the reading sounder operated by the receiving relay on the single-current side of the quadruplex. These accessories are variously referred to as "bug-traps," "uprighters," etc., and their application and action will be described in connection with quadruplex systems.

THE "POLAR" RELAY

All of the inherent difficulties experienced in the operation of single Morse lines, are encountered in the operation of the single-current differential duplex system.

During favorable weather and where a high degree of line insulation is maintained, both of these methods of telegraphy are satisfactory. But, when, due to excessive leakage conductance the current values at the receiving end are low, considerable difficulty is experienced in maintaining satisfactory operation.

The polar duplex overcomes this difficulty to a great extent, and by means of this system lines may be worked satisfactorily long after adverse weather conditions have rendered single Morse, and single-current duplex systems inoperative.

Figure 223 shows a theoretical view of the magnetic circuit of the polar relay.

It will be seen that the windings are identical with those of the ordinary single-current differential relay. Current from the battery flows through

the windings in opposite directions, the action of one coil neutralizing that of the other, the result of which is that the core is not magnetized so far as any action due to the current from the battery is concerned.

The fundamental difference between the two instruments is that in the polar relay the tongue is held on either side due to the magnetic pull of the permanent magnet which constitutes the cores of the electromagnets.

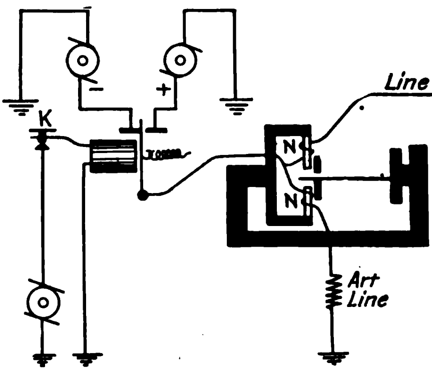


FIG. 223.—Theory of the differential polarized relay.

In the case of the common differential relay the armature tongue is held in the closed position by the action of either or both magnet coils, and in the open position by the action of a retractile spring which withdraws the armature from the closed position when the coils are not energized. The armature of the polar relay is held in the closed position and in the open position by the attraction of one pole of the permanent magnet, and it is necessary of course that the armature be drawn into contact with the open or the closed pole due to magnetism in the cores, resulting from the action of current in either coil of the instrument. The important feature is that after the armature has once been attracted toward either contact, it will remain there whether current remains in the coil winding or not (provided there is no current in the opposite coil).

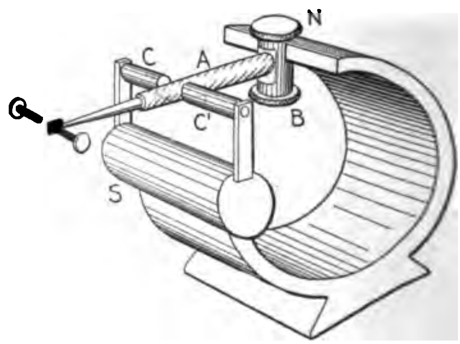


FIG. 224.—Permanent magnet and armature suspension of the Siemens polar relay.

Referring to Fig. 223: When the key *K* is operated, the armature lever of the pole-changer is caused to make contact, first with the negative battery terminal and then with the positive battery terminal. If the ohmic resistances of the real line and the artificial line are equal, current from whichever dynamo is connected with the armature lever will go through the companion windings of the relay differentially, with the result that there is no electromagnetism produced in the cores facing the relay armature. It matters not whether the out-going current is from a positive source or from a negative source: owing to the fact that it passes through the windings of the relay differentially there will be no mag-

netism produced, and this, irrespective of the polarity of the current flowing in the circuit.

If the key K is manipulated, there will be sent out a series of impulses alternating in sign, from positive to negative each time the key is closed and opened, and if the resistance of the artificial line side of the relay balances that of the line side, the armature of the relay will not be affected. Moreover, it will be found that if the relay tongue is moved by hand into contact with its closed contact or with its open contact, it will still remain passive to the out-going reversals from the pole-changer.

In one of the older standard patterns of polar relay, which is known as the Siemens, or "camel-back" relay, Fig. 224, a comparatively large permanent magnet has mounted on one end two cross-pieces made of soft iron which form the cores C and C' of the main-line and artificial-line coils.. From the other extremity of the permanent magnet the armature A is suspended, being pivoted in a brass casing, that is, it is pivoted in bearings, which, being non-magnetic, introduce a gap between the pole-face of the large permanent magnet and the armature. The latter is magnetized inductively across the existing air-gap, to a degree sufficient to create the desired attraction between the free end of the armature and the cores of the magnets, both of which are of identical polarity, and opposite to that of the extremity of the permanent magnet at which the armature is pivoted. In the completed instrument, the cores C and C', carry the coil windings of the main-line magnet and the artificial-line magnet respectively. If it is assumed that the end B of the permanent magnet at which the armature is pivoted is the north pole, then the free end of the armature is also of north polarity, and, owing to the fact that both cores of the electromagnets are attached to the south pole of the permanent magnet, and taking that polarity, it is evident that the armature will cling to whichever core it may be placed in contact with. That is, it will cling to either the open contact, or to the closed contact when no current traverses the windings of the electromagnets, or when current flows through the windings differentially.

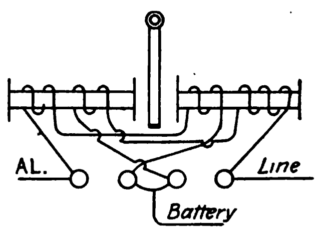


FIG. 225.—Coil windings of a differential polarized relay.

The magnets of polar relays are usually so wound that when current from the distant station flows through the main-line coil, it is given a path through an auxiliary winding in the opposite coil, in the reverse direction (Fig. 225), which results in the permanent induced magnetism in one of the cores being neutralized, while the magnetism existing in the other core is intensified, causing the armature to be attracted toward the opposite contact. The reverse action takes place when the battery poles at the home station and at the distant station are in opposition (like poles to line) in

which case the artificial-line coil of the home relay has its magnetism increased, and the line coil has its magnetism neutralized. Thus, due to the action of the current in the coils, the armature is caused to move into contact with the open or the closed contact as desired.

The office of the auxiliary winding in each case is to act as a "clearing out" agency.

There are several distinct types of polar relay used by the various telegraph administrations, each relay having its peculiarities of design, but the principle upon which all polar relays operate is the same.

Figure 226 illustrates the form of polar relay used by the Postal Telegraph-Cable Company. It differs from the type of instrument previously described in that the permanent magnet used to magnetize the armature, or rather the "armatures" in this case, is situated under the base of the instrument.

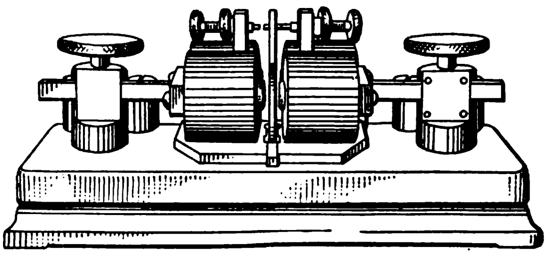


FIG. 226.—Type of polar relay used by the Postal Telegraph-Cable Company. The permanent magnet is mounted under the base.

Among the other types of polar relay in use might be mentioned the "Krum" relay, which instead of employing permanent magnets to hold the armature in connection with the open or the closed contact of the local sounder circuit, has an extra pair of magnets, one beside the main-line and one beside the artificial-line magnets, which are constantly charged from a separate source of current, serving the same purpose as the permanent magnet used in other types of relay.

Another efficient type of instrument is that known as the Wheatstone polar relay, in which the pivot of the vertical armature rests on one end, thus effecting a considerable reduction in the mechanical inertia of the moving element. Also, the magnet coils are somewhat longer than in the ordinary types of relay. The windings have a comparatively high resistance, but as they are connected in multiple for high-speed work, the total resistance is reduced to one-fourth, and the time-constant of the relay, as an indirect result is also reduced. In this type of relay there are two armatures, both mounted on a common shaft, and so situated that their lower ends are under the influence of a permanent magnet. Each relay is equipped with

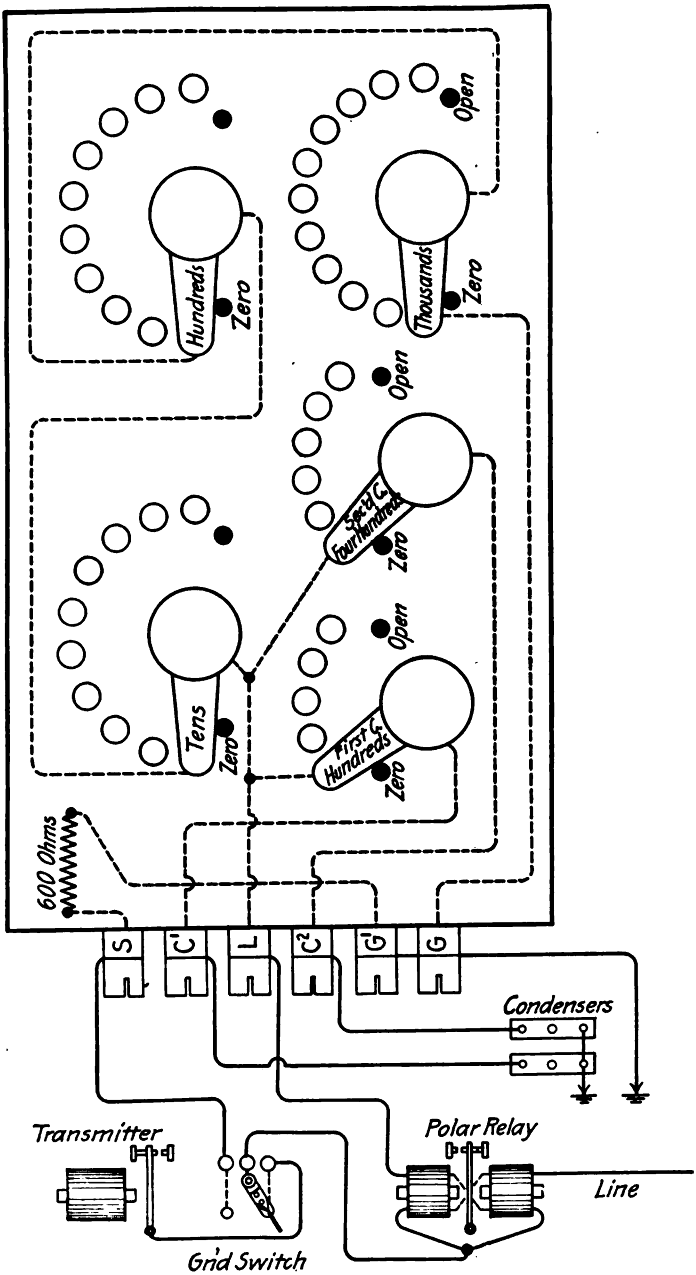


FIG. 227.—Binding-post and internal connections of artificial line rheostat—Postal type.

four magnets, and when current traverses the windings; two poles repel and two poles attract the armature.

The artificial line rheostat, and the artificial capacity used in connection with polar duplex apparatus to "balance" the resistance and capacity of the actual line are illustrated theoretically in Fig. 219.

Figure 227 shows the actual internal and external connections of the rheostat and the condensers which make up the artificial line. The particular type of rheostat illustrated is that used by the Postal Telegraph-Cable Company. It will be seen that the artificial line side of the polar relay is connected to the binding-post *L* of the rheostat, from which point there is a circuit to ground, via the resistance coils, marked "tens," "hundreds," and "thousands," by means of which the total resistance of the artificial line may be varied from zero to 11,100 ohms in order to balance the resistance of any line wire which may be connected into the set. It will be noticed also, that from the binding-post *L* there are two condenser circuits to ground, the first and second condensers being in series with variable timing resistances. The first and second group of resistance coils are connected with binding-posts C^1 and C^2 respectively, via rheostat arms which may be moved from one contact button to another; so to insert any desired value of timing resistance in series with the condensers.

Each of the condensers has a capacity of 3 microfarads, and as they are connected in parallel, there is available a total capacity of 6 microfarads with which to balance the static charge and discharge effects of the actual line. The capacity of the condensers being variable, any desired capacity may be obtained simply by turning a knob mounted on the top of each condenser. The "ground" switch shown to the right of the transmitter, or pole-changer, when thrown to the right, places the home battery to line. For the sake of clearness the main-line battery connections are omitted from Fig. 227, but it is understood that when the armature tongue of the transmitter is in the closed position as shown, main-line battery of one polarity is connected to line, and when the tongue is in contact with the back-stop, battery of the opposite polarity is connected with the line by way of the ground switch and the polar relay.

When the ground switch is thrown to the left, it is evident that the home battery is disconnected from the line, and that the incoming signals after passing through the relay have a path to ground via a 600 ohm resistance coil contained within the rheostat box. The location of this ground-coil should be kept in mind, as, presently we shall again refer to it in connection with "balancing."

OPERATION OF THE POLAR DUPLEX

Figure 228 shows the connections of the main-line and local circuits of the polar duplex.

Complete equipment at both ends of a duplexed circuit are shown so that the various operations may be treated with regard to their effects upon the apparatus at both ends of the line.

PC and *PC'* are the pole-changers at stations *A* and *B* respectively while *PR* and *PR'* are the polar relays, *K* and *K'* the signaling keys, locally controlling the movements of the pole-changer armature in each case.

The dynamos which furnish current for the operation of the main-line relays, are shown, two at each end. In each case one of the dynamos has its positive terminal connected with the back-stop of the pole-changer, while

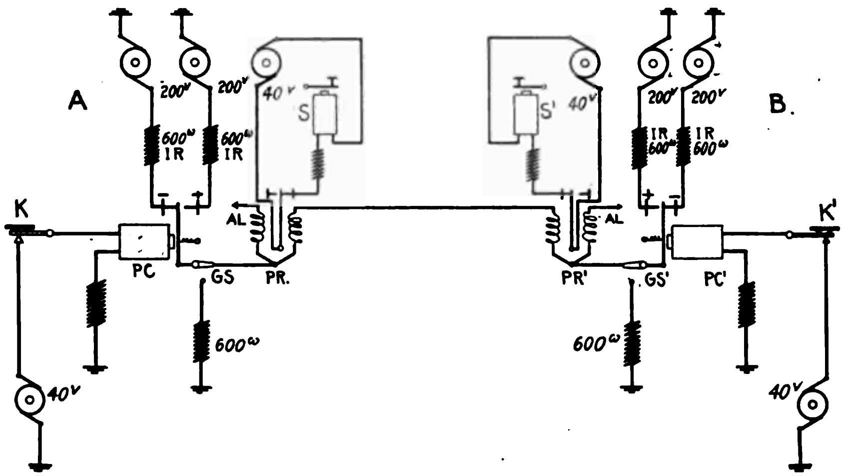


FIG. 228.

the other dynamo has its negative terminal connected with the closed-contact of the pole-changer.

The resistance coils and condensers which comprise the artificial line, are, at each end of the main-line circuit; marked *AL*.

In Fig. 228 the pole-changers at each end of the line are closed, that is, the armature levers of the pole-changers in each case are in contact with their front-stops, due to the fact that the signaling keys *K* and *K'* are closed, This places to line at each end a 200 volt negative battery. As the batteries are of equal potential, no current will flow over the main line. At the instant both pole-changer armatures make contact with their back-stops—thus placing opposing battery to line—the levers of the polar relays at each end are moved into contact with their back-stops, thereby opening the local reading sounder circuits at each end.

At this point it is important to gain a correct understanding of why the armatures of the polar relays at each terminal station are attracted toward either contact when the main-line batteries at each end of the line are in opposition. The explanation is that when the terminals of a wire are at

equal potentials, no current will flow in the wire. Therefore, when like poles of identical potential are to line, as in the case before us, it is apparent that the terminals of the main-line wire are at equal potential. An entirely different condition, however, exists with regard to the artificial line at each end. As, in each case, one end of the artificial line is connected with the earth (which is at zero potential), there is presented to the outgoing currents from each station a path to ground via the artificial line magnet of the polar relay. On each occasion, therefore, when like poles are to line at each end, current from the home battery flows through the artificial line and the armature of the polar relay is attracted toward its back-stop if the opposing batteries are positive and toward its front stop if the opposing batteries are negative.

In order to carry on transmission in both directions at the same time it is necessary that the operator at *A* shall be able to control the movements of the armature of the relay at *B* regardless of which pole of his battery *B* has to line. Also that the operator at *B* shall be able to control the movements of the relay armature at *A* regardless of which pole of his battery *A* has to line.

Suppose the operator at *B* should depress his key (while the key at *A* is open), thereby placing the tongue of his pole-changer in contact with the negative pole of the main-ine battery at *B*, the result will be that the main-line coil of the relay at *A* will be energized and its tongue attracted toward its closed-contact, thereby operating sounder *S*.

It is evident, of course, that current continues to flow through the artificial line coil of the relay at *A*, but owing to the fact that the current strength in the main-line coil of the relay is twice that in the former, and in the opposite direction, it is plain that the magnetism in the core of the relay at A is reversed, and the armature, as a result thereof, moves into contact with its front-stop. If what has previously been stated is true, the armature of the relay at *B* should have remained passive to the reversal of current sent out from *B* when the key at *B* was closed. That this is so is apparent, for, although the magnetism in the artificial line magnet of the relay at *B* has now been neutralized due to the presence of current in the main-line coil of the relay, the armature is held in the open position by the action of the permanent magnet associated therewith. In other words, nothing has happened so far to cause the armature of the main-line relay at *B* to change its position, therefore, it remains in the position taken when last it was caused to move by a surplus of magnetism in one coil over that obtaining in the other magnet coil. Similarly, when *A* alone closes his signaling key, the relay at *B* responds, while the relay at *A* does not. When the signaling keys at both ends are depressed, the line currents once more are in opposition, and, as in this case the currents flowing through the artificial lines at each end are in the reverse direction of that taken when both keys were open, the relay armatures at each end are caused to move into contact with their front-stops.

In effect, therefore, when the operator at A attempts to register a "dot" on the relay at B, at the same instant that the operator at B intends to register a "dot" on the relay at A, each station causes to be produced in his own relay the signal intended to be transmitted from the distant end of the line. Or, the foregoing might be paraphrased thus: the relay at A will be closed whenever the key at B is depressed, regardless of whether A is sending or idle; and the relay at B will close whenever the key at A is closed whether B is sending or idle, but in neither case will the signals transmitted from either end conflict with those originating at the distant station.

SEVERAL DUPLEX SETS WORKED FROM ONE PAIR OF DYNAMOS

In the duplex circuit diagrams heretofore given, two dynamos have been shown at each station as an integral part of each set. It should be understood, however, that in practice, two machines, one delivering a positive potential and the other a negative potential, are used to supply current for a number of lines.

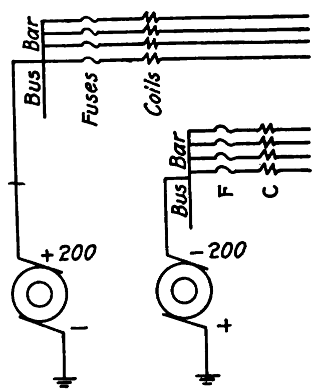


FIG. 229.—Several duplex sets worked from one pair of dynamos.

In Fig. 229, two 200-volt dynamos of opposite polarities are shown connected to separate busbars. Instead of four wires leading therefrom to pole-changers of duplex and quadruplex sets, any number of sets may be connected thereto, depending upon the capacity of the dynamos employed.

The four wires shown in Fig. 229 leading from the positive busbar are connected to the back-stops of four different pole-changers, and the four wires leading from the negative busbar are connected to the front-stops of the same four pole-changers. One pair of machines, therefore, serves to operate four or more duplexes.

Each separate branch is fused, and has in series with the fuse F, a protective resistance coil C, or a lamp which in any case may have a resistance of 200, 300 or 600 ohms, depending upon the value desired in any circuit that may be connected thereto.

"LOCAL" CIRCUIT CONNECTIONS

In the preceding text-matter describing duplex-circuit operation, in several instances reference is made to the "open" and "closed" contacts of relays, transmitters and pole-changers.

It might be here stated that instead of employing one dynamo to operate

each pole-changer, each sounder, etc., one machine having an output of 6 volts, 24 volts, 40 volts or any desired e.m.f. (depending upon the resistance of windings of local instruments, and upon the current values desired) may be availed of to feed a large number of such circuits.

Figure 230 shows four separate leads from a 40-volt positive busbar, two of which are shown connected to local circuits. The upper wire is connected through the magnet winding of a pole-changer, via a circuit controlling key. The opposite terminal of the winding is connected to ground through a current regulating resistance coil *C* which may have any desired value. Inasmuch as the negative terminal of the dynamo is permanently grounded, closing the signaling key establishes a completed circuit through the winding of *PC*

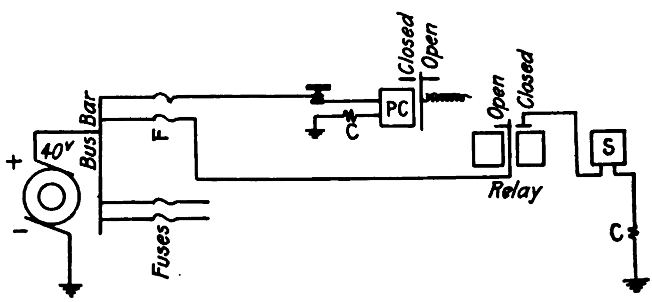


FIG. 230.—Several duplex and quadruplex local circuits operated from a common source of e.m.f.

and ground coil *C*, thus energizing the magnet of *PC*, and causing the armature tongue to move into contact with the front-stop, or closed pole. When the key is opened the circuit is broken, permitting the retractile spring to pull the armature tongue into contact with the back-stop or open pole.

The second wire (Fig. 230) leading from the busbar of the local circuit dynamo is shown connected with the armature tongue of a relay. When the electromagnet of the relay is energized due to the presence of current in the main line connected through it, the armature is attracted toward the closed contact, meaning that the circuit starting at the local dynamo is extended through the relay armature, closed-contact, and on through the magnet windings of the sounder to ground through the resistance coil *C*.

THE BATTERY DUPLEX

Figure 231 shows the theoretic connections of the main-line instruments used to operate a polar duplex by means of gravity battery.

In this duplex arrangement the pole-changer consists of two double-contact relays, or transmitters. The transmitters are connected in series, that is, one signaling key controls the operation of both instruments, so that both

armatures are in the closed position at the same time, and in the open position at the same time; depending upon whether the key is open or closed.

It will be seen at a glance, that when both armature levers are in contact with their back-stops the positive pole of the row of gravity cells is connected

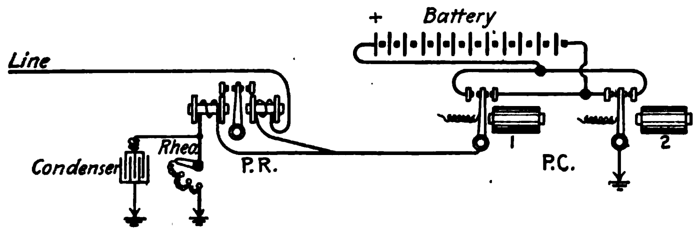


FIG. 231.—Theory of the gravity battery duplex.

to line via the tongue of transmitter No. 1, and at the same time the negative pole of the battery is "grounded" via the tongue of transmitter No. 2. Conversely, when the signaling key is closed and both tongues are against their front-stops, the negative pole of the battery is connected to line, and the positive terminal of the battery to ground. The operation of the key; con-

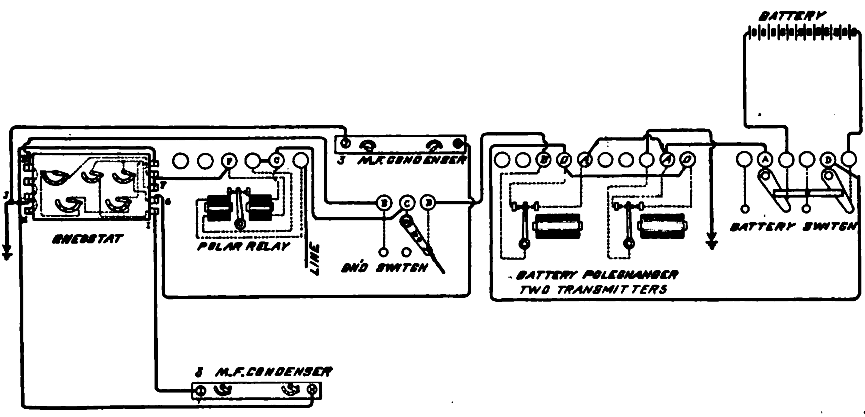


FIG. 232.—Actual connections gravity battery duplex.

trolling as it does simultaneously the operation of both transmitters, results in alternate positive and negative impulses being sent to line, the same as when two dynamos of opposite polarities are used.

In other respects the connections are the same as in the dynamo polar duplex.

Figure 232 shows the actual circuit connections of the battery duplex.

THE "BRIDGE" DUPLEX

The single-current duplex, and the polar duplex, being based on the differential principle are dependent upon producing an equality of current strengths,

while the bridge duplex which is based upon the well-known Wheatstone bridge principle is dependent upon producing an equality of potentials.

Figure 233 shows two stations *A* and *B* at either end of a line wire equipped with bridge duplex apparatus.

B and *B'* are the main-line batteries at *A* and *B* respectively. *AL* in each case represents the artificial line at either end. *R* and *R'* are two artificial resistances of equal value, likewise *r* and *r'* at station *B*. At each end of the line the relays are connected between the points *c* and *d* of the "bridge" formed by the line wire and the artificial line resistance. Closing the key at *A* sends out a current which divides at *a*, half passing over the line wire to station *B* and reaching earth via the apparatus at that end of the line, while the other half passes through the artificial line at *A*, reaching the earth

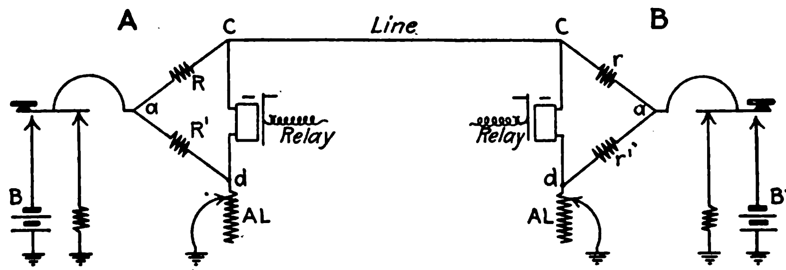


FIG. 233.—Theory of the bridge duplex.

at that end of the circuit. Inasmuch as the points *c* and *d* are equidistant, ohmically, from the point *a*, their potential values are identical, and no current will flow through the windings of the relay at *A*. This is true, of course, only when the resistance of the artificial line at *A* is made equal to the resistance of the actual line to ground at the distant end. The relay at *A*, therefore, is not affected when *A* sends to *B*. The same condition prevails when *B* alone sends to *A*. Signals from *A* operate the relay at *B* because the incoming signals have a joint path made up of the branches *c–d* and *c–a*, thus setting up a difference of potential between the points *c* and *d* sufficient to operate the relay.

The operations which take place with different key combinations at either end of the bridge duplex may be traced without difficulty.

Since the line relay employed in the bridge duplex does not need to be differentially wound, it is evident that any ordinary relay may be used with this method of duplexing. It is apparent, also, that the outgoing currents do not pass through the windings of the home relay, and, as the currents pass directly to line, there is a minimum amount of retardation in the sending circuit. And, further, it is claimed for the bridge duplex that its line relays, on account of their position in the bridge, are not as responsive to induced line disturbances or to earth currents as are the line relays in the

differential duplex. This is due to the fact that in the bridge system only a portion of the line currents pass through the relay, no matter whether the currents are the result of an impressed e.m.f., of induction, or of conduction from neighboring circuits, while in the differential duplex all currents existing in the main line pass through the windings of the line coil of the relay.

The bridge duplex has been more highly developed in Europe than in America, and several of the refinements applied to its operation there are particularly noteworthy as having a bearing on the general subject of high-speed signaling.

These refinements include the application of the signaling condenser and the reading condenser, Fig. 234.

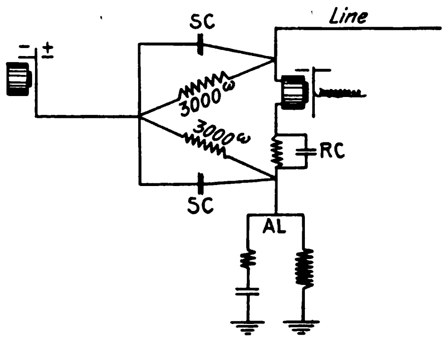


FIG. 234.—Signaling condensers and reading condenser applied to the bridge duplex.

SIGNALING CONDENSERS

As has previously been stated, the electrostatic capacity of the line wire must be satisfied in any given case before final-current values obtain in the circuit. Although the time required for the current to reach its maximum value is independent of the value of the e.m.f. employed, the time required for the current to reach a certain percentage of its final value is directly dependent upon the value of the potential applied to the circuit.

It is well known that when a terminal potential of, say, 250 volts is applied to a line the required operating current strength will actuate the relay at the remote end of the line in approximately half the time required to produce the same effect with an applied e.m.f. of 125 volts. Calculations of this kind, of course, require that the current resulting from the lower value of e.m.f. will have sufficient strength to operate the relays satisfactorily. If, now, we consider the circuit conditions prevailing when the signaling condensers *SC* (Fig. 234) are connected in shunt with the bridge resistance, it may be seen that the presence of these condensers, in effect, create

a momentary short circuit around the 3,000-ohm bridge resistances. This interval, although brief, is sufficient to permit of the application of maximum battery potential to the line, which results in an initial current value at the distant end of the line, equal to that which would obtain if the 3,000-ohm resistance were not a part of the circuit. After the condenser and the line have become charged by the initial impulse, the final-current strength builds up through the circuit which includes the 3,000-ohm resistance as a portion thereof. The ultimate value of the current in the circuit will, therefore, be less than that at first prevailing at the receiving end. Obviously the final current strength will have an $\frac{E}{R}$ value.

Inasmuch as the 3,000-ohm bridge coil on the artificial line side also is shunted with a condenser having a capacity adjusted to a value equal to that shunting the 3,000-ohm bridge coil in the line side, it is plain that exactly like conditions exist in each branch of the circuit at the same time.

When the line current is reversed it is obvious that the condensers will discharge in a direction coinciding with that due to the alternate battery pole. Thus the total value of the e.m.f. actuating the circuit will be that of the terminal battery plus that existing as charge in the condensers.

On each occasion, therefore, that the condensers are taking on or giving up their charge, the initial portion of the signaling impulses in either direction has a path other than that presented through the 3,000-ohm bridge coils. It may be observed that the effect of the condenser discharge is to greatly expedite the discharge of the line wire, and in this regard it is found that the best results are attained when the capacity of the condenser is made equal to that of the line.

THE READING CONDENSER

The reading condenser, or "shunted" condenser as it is sometimes called (*RC* Fig. 234), in British Post Office practice consists of a group of three resistance units having individual values of, 2,000, 4,000, and 8,000, ohms or a total of 14,000 ohms, shunted by an adjustable condenser having a total capacity of 7 1/2 microfarads.

The function of the shunted condenser is to balance the effects of self-induction of the signaling relay.

In a preceding chapter it was pointed out that when the direction of current flowing in a coil of wire or a magnet is reversed the effect of self-induction between the turns of wire in the magnet is, in the first place, to retard the rise of current strength in the circuit of which the winding forms a part and when on each occasion the circuit is opened the effect of self-induction is to delay the fall to zero current.

The presence of the shunted reading condenser provides that the com-

mencement of the reversal of magnetism in the cores of the relay will take place at the instant the transmitter tongue at the distant end of the line leaves either the positive or the negative battery contact, so that the process of reversing has progressed to a certain extent by the time the tongue of the distant transmitter reaches the opposite battery contact, or the ("ground") contact, as the case may be, and an effect is produced which balances the effects of self-induction by hastening the rise and fall of the operating current in the circuit at the instant desired.

The amount of capacity and resistance which yields the best result in a given case, naturally is dependent upon the particular properties of the line conductor under consideration, and can be determined only under working tests.

THE WESTERN UNION BRIDGE DUPLEX

Figure 234*a* shows the theory of the bridge duplex recently adopted by the Western Union Company. In this duplex the bridge arms consist of

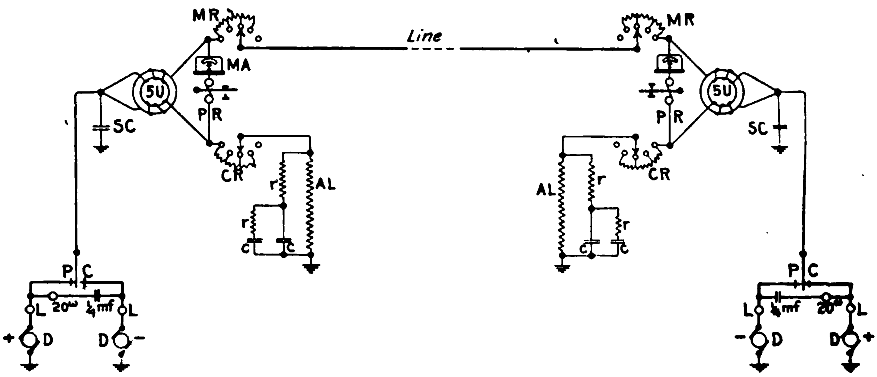


FIG. 234*a*.—Western Union bridge duplex.

the companion windings of an impedance coil (5*U*) each arm having an ohmic resistance of 500 ohms (see the impedance coil, Fig. 279).

In Fig. 234*a*, the main-line circuits at each end of a duplexed line are shown, in which *D* represents the main-line dynamos, *L*, resistance lamps, *MA*, milammeters, *PR*, polar relays, *PC*, pole-changers, *r*, retardation resistances, 5*U*, impedance coils, *SC*, spark condensers, *MR*, main-line adjustable resistances, *CR*, compensating-circuit adjustable resistance, *AL*, regular artificial-line adjustable resistances, *C*, static compensating condensers.

The operation of this duplex will be better undertsood after the reader has gone through the matter describing the Western Union quadruplex (Fig. 276).

THE HIGH-POTENTIAL "LEAK" DUPLEX

In those telegraph installations where the only dynamos in service are those required to operate the long quadruplexes, the "leak" method of reducing high potentials to values sufficient to operate circuits duplex, is sometimes employed.

This method is due to Mr. Minor M. Davis and was introduced on the lines of the Postal Telegraph-Cable Company several years ago.

Figure 235 shows the theoretic arrangement of circuits of the leak duplex.

An artificial circuit to ground is built up of coils having resistances of 800 plus 2,200 ohms, or a total of 3,000 ohms.

Where the machines available for quadruplex working have potentials of 380 volts, positive and negative, respectively, it is apparent that with

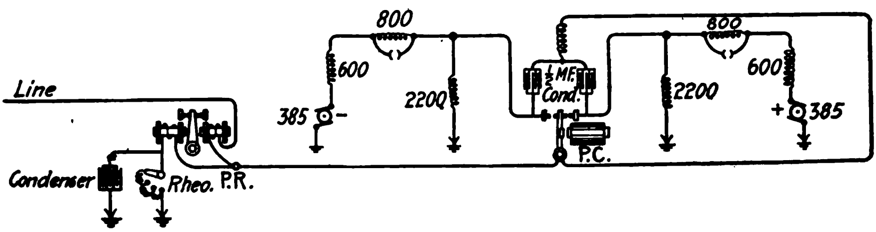


FIG. 235.—Theory of the high-potential "leak" duplex.

an internal resistance of 600 ohms in series with the leak resistance, the nearest ground is 3,600 ohms distant from the battery, at least that would be the case when the tongue of the pole-changer is midway between its back-stop and front-stop.

As the pole-changer is operated its tongue is caused to make contact with the leak circuit at a point either $\frac{1400}{3600}$ of the total ohmic distance to ground, or in case the 800-ohm resistance is short circuited at a point $\frac{600}{3600}$ of the total ohmic distance to ground. Thus the available voltage at the pole-changer contacts is reduced to a value considerably below that available at the brushes of the machines. The exact value in either case may be calculated by means of either of the methods described in a preceding chapter for determining the difference of potential at any point along a conductor possessing resistance—between that point and ground.

A leak path to ground is provided for each of the high-voltage generators, so that the reduction of voltage may be made equal in the case of both positive and negative machines.

The possible connections are such that three different potential values may be availed of as desired.

When the circuit-controlling plugs are removed from the 2,200-ohm

coils, and the 800-ohm coil in each circuit is short circuited, the full quadruplex battery is available. With the 2,200-ohm coils in circuit while the 800-ohm coils are short circuited, the next lower potential is available, and when the 2,200-ohm coils are in circuit and the shunt circuit removed from around the 800-ohm coils, a third potential value is available.

Figure 236 shows the actual binding-post connections of the main-line wiring of a high-potential leak duplex.

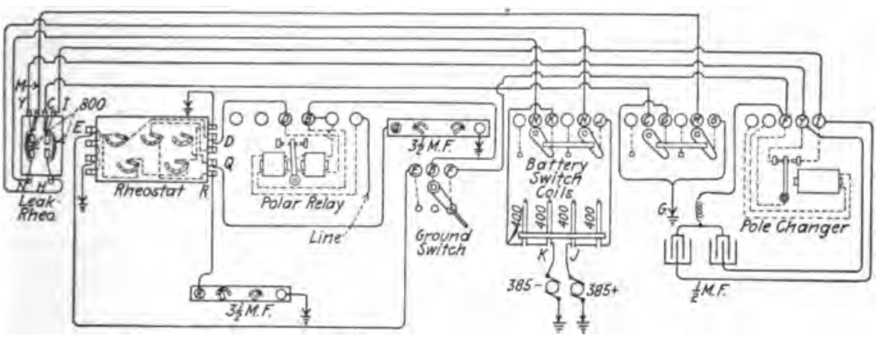


FIG. 236.—Actual connections of the high-potential leak duplex.

HIGH EFFICIENCY DUPLEXES

Within recent years a demand has been created for the development of a high efficiency duplex. Among the causes which have brought about this demand, the more important are: the increasing amount of line disturbance experienced due to induction from other wires of the same system

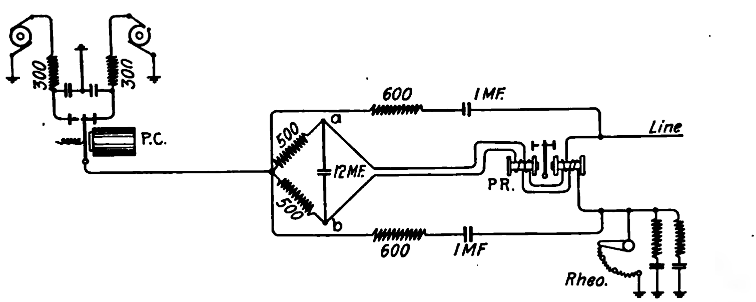


FIG. 237.—Theory of the high-efficiency duplex employed by the Postal Telegraph Company.

and from neighboring conductors carrying high potentials, decrease in the efficiency of transmission attributable to the employment of semi-automatic transmitters which are not as regular in action as simple hand transmission by means of the Morse key. Also, the call for fast and dependable leased

wire service and for high-speed automatic and printer circuits has resulted in a systematic critical investigation of the duplex at the hands of several well-known experts. Fig. 237 shows the circuits of an improved differential duplex recently brought out by Messrs. Davis and Eaves. The principles of operation are the same as in the ordinary differential polar duplex previously described, but several capacity and resistance units have been combined and applied in such relation to the regular duplex circuits that not only do they serve to correct the inherent weaknesses of the duplex, but to bring about action in certain places and at certain intervals which materially increases the operating efficieny of a duplex to which these adjuncts are applied.

By referring to Fig. 237 it will be seen that two 500-ohm non-inductive coils have been introduced at the "split" behind the relay, so that the outgoing current has a joint path, on the one hand through a 500-ohm coil and the main-line winding of the relay, and on the other through the companion 500-ohm coil and the artificial-line winding of the relay. The presence of these coils introduces only the property of resistance into the circuit, as owing to the fact that they are non-inductively wound there is no retardation introduced. The insertion of the resistance back of the relay steadies the balance somewhat, due to the fact that a considerable proportion of the total resistance of the circuit is inserted between the coils of the relay and the ground connection via either dynamo. The presence of the two 500-ohm coils causes the condenser connected in shunt therewith to take on a charge due to the difference of potential which exists between the points *a* and *b* when the pole-changer at the distant end of the line is operated.

The function of this condenser is to hasten the "turn-over" of magnetism in the cores of the home relay when the distant station sends out current reversals. The condenser anticipates, as it were, the action which will result in the home relay when the tongue of the pole-changer at the distant station reaches the negative or positive battery contact, as the case may be.

With the ordinary arrangement of duplex circuits, the armature lever of the home polar relay remains in contact with the closed contact of its sounder circuit as long as the tongue of the pole-changer at the distant station is in contact with its front-stop and until the pole-changer tongue again touches its back-stop.

The action of the condenser here considered is to cause reversal of magnetism in the relay at the instant the tongue of the pole-changer at the distant station departs from either its front- or back-stop. It is apparent that the charge which the condenser has accumulated while the tongue of the distant pole-changer has been in contact with either battery pole will discharge through the windings of the home relay in a direction coinciding with that taken by the current resulting from the next succeeding battery contact at

the distant end. Thus, the current arriving from the distant station completes the work already begun by the condenser.

The two 600-ohm non-inductive coils connected around the relays, in series with one-half microfarad condensers, present to in-coming inductive disturbances a path to ground which does not lead through the windings of the relay, thus in large measure making the relay immune to induced currents, especially from alternating-current sources, and also to electrostatic and electromagnetic induction from neighboring wires of the same system.

Another benefit derived from the 600-ohm, 1-m.f. shunt circuit is that the discharge due to self-inductance of the relay magnets takes place through the loop circuit thus formed around the relay coils, preventing its interference with line currents.

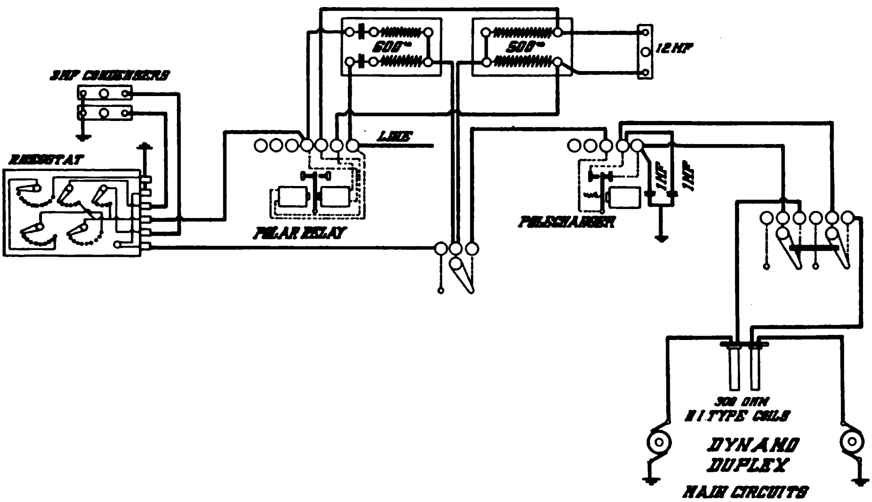


FIG. 238.—Main line connections of the Postal Company's duplex.

Another decided advantage resulting from the employment of the latter circuit is that the first part of each out-going current wave gets to line and to the distant station earlier than it would if required to travel through the inductive winding of the home polar relay. The desired movement of the armature of the distant polar relay, therefore, is well under way by the time the Ohm's law current arrives.

Other important features have been introduced in connection with this high efficiency duplex, among which might be mentioned the use of an improved "spark-killer" arrangement to control the sparking which occurs at pole-changer points as contact is alternately made betweeen the tongue and the positive or negative potentials.

Also, a reduced internal-resistance value is inserted between the dynamo

and the pole-changer line contacts, and an improved form of polar relay is used.

These features are referred to in detail further along.

Figure 238 shows the instrument main-line connections of the high efficiency duplex just described.

CITY LINE DUPLEX

Figure 239 shows the theoretical connections of a short-line duplex, which may be operated over a single wire with main battery of one polarity, at one end of the line

The line relay at the main office is an ordinary differential non-polarized instrument, the same as that used in connection with the ordinary single-current duplex, or on the second side of a quadruplex. At the branch office

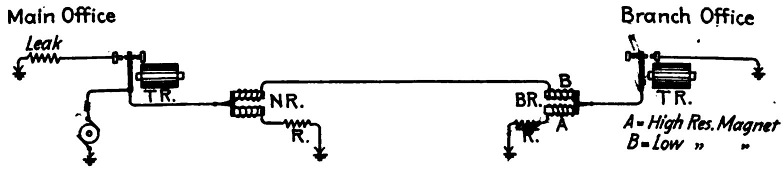


FIG. 239.—City line duplex.

a special non-polarized differential relay is employed, the artificial-line coil of which has a winding of higher resistance than that of the main-line coil.

A glance at the circuit arrangements will show that battery is to line at all times, full potential when the main-office transmitter is closed, and a reduced potential when the main-office transmitter armature is in contact with its back-stop: the value of the reduced potential depending upon the resistance value of the leak circuit which forms one path of a joint circuit to ground, the other path consisting of the main line and the apparatus at the branch office, and the path to ground via the artificial line at the main office.

When the armature lever of the relay at the branch office is resting against its back-stop, the only path presented to the incoming signals is through the coils of the relay to ground via the artificial line at the branch office. When the main office only is sending, it is evident that inasmuch as the out-going currents pass through the relay at the main office differentially, the armature of that relay is not affected, while the relay at the branch office responds each time the armature tongue of the main-office transmitter closes, and opens each time the tongue of the main-office transmitter is withdrawn into contact with its back-stop, because then the current which is sent to line is not of sufficient strength to operate the branch-office relay. Obviously, the tension given the retractile spring attached to the armature of

the branch-office relay must be such that the magnetism produced by the reduced current volume will not be strong enough to attract the armature.

With the armature tongue of the branch-office transmitter in the closed position, and at rest, the incoming signals have a joint-path to ground at the

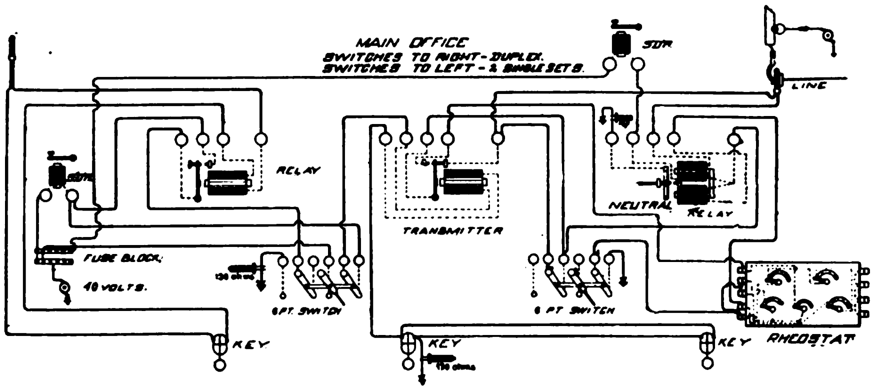


FIG. 240.—Main office connections city line duplex.

branch office, but still the armature of the relay at the branch office will respond each time the main-office transmitter is closed, and release each time the latter is opened, for although a greater current volume exists in the main line because of the shorter path to ground presented, the total amount of

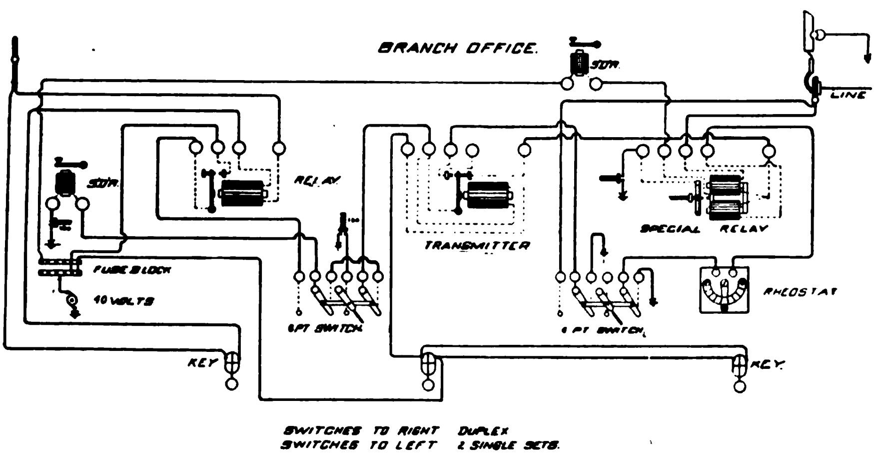


FIG. 241.—Branch office connections city line duplex.

magnetic pull on the armature of the branch-office relay is no greater than before owing to the fact that the high resistance (and the most effective) coil of the relay is practically short-circuited by the newly presented path to ground via the tongue of the transmitter.

It is apparent, however, that when the armature lever of the branch-office relay is in contact with its front-stop the increased current strength in the main-line coil of the main-office relay results in the armature of that relay being attracted—the very result desired, for it is when the tongue of the branch office transmitter is moved into contact with its front-stop that the armature of the main-office relay should be moved into contact with its front-stop.

The reason why this type of duplex is not suitable for long lines is that the ratio of operating to releasing current is such that the margin of current strength between these two values is not very great, in fact, not great enough to permit of fluctuation of current strengths such as experienced in the operation of long lines.

Figure 240 shows the actual main-line and local connections of the city-line duplex at the main office, while Fig. 241 shows the connections at the branch office.

At the main office a regular duplex rheostat is used; the artificial-line circuit being made up of the regulation artificial-line coils, and the "leak" circuit to ground being made up of the coils ordinarily used as the first and second condenser circuits. As the arrangement is intended only for short lines, it is not necessary to employ static compensating condensers.

SHORT-LINE DUPLEX, WITH BATTERY AT ONE END ONLY.

A short-line duplex requiring battery at one end only, which has been employed with considerable success on the lines of the Western Union Telegraph Company, is that known as the Morris duplex.

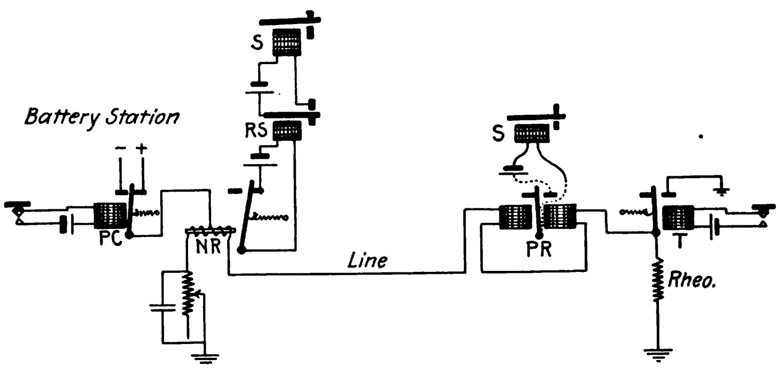


FIG. 242.—Double current duplex with battery at one end only.

The system was originally devised by Mr. Gerritt Smith, later improved by Mr. Morris, and still more recently has been equipped with static compensating accessory apparatus which permits of its successful employment in the duplex operation of lines 150 miles or more in length.

Figure 242 shows the theoretical main line, and the local connections of the latest arrangement of apparatus.

The rheostat at the main, or battery station, makes possible the insertion of a resistance value equal to that of the line wire plus the resistance of the rheostat at the distant office.

The proper resistance value required to be inserted at the distant office may be determined by measuring the line current with the distant key open, and again when it is held closed. The resistance of the rheostat should be such that with the key closed the line current will be three times that obtaining in the circuit when the key is open.

The proper resistance value to give the rheostat at the battery end of the line may be determined by measuring the resistance of the line to the distant ground including the resistance of the distant relay and rheostat.

The operation of this duplex may easily be traced by observing what takes place when the keys are operated, and when the transmitter tongues at either end are in the various possible positions.

SPARKING AT CONTACT POINTS

In the operation of relays a troublesome spark is produced as contact is made or broken between the movable armature lever and the stationary front-stop each time the local circuit is closed or opened. It is the effect of the extra current of self-induction, and is strongest at the instant the circuit is broken. Naturally, it is more pronounced in wet than in dry weather, owing to the fact that the forward and the backward movement of the armature of the relay is then more sluggish. The same is true in any state of the weather of relays operating in lines which are not maintained at a high degree of insulation.

It has been found that the more rapid the movement of the armature, the less pronounced will be the resulting spark at make and break of contact.

The effects observed in the operation of telegraph apparatus are in conformity with the general theory of the subject as enunciated by Faraday, and point to the conclusion that if connections and disconnections could be made rapidly enough "sparkless" make and break might be accomplished. Rayleigh has shown that when a circuit is broken at velocities of the order of one meter (39.37 in.) per second, there is no evidence of sparking between contact points.

It is found that with a quick-moving armature, a much closer adjustment is possible than with a slow-moving armature. If the current traversing the magnet windings of the instrument is weak, thus necessitating a weak retractile spring, it is found that a wide adjustment between tongue and contact point is necessary in order to avoid sparking, but with a strong magnetic pull on the armature, and a strong retractile spring, insuring quick

movement of the armature in each direction, points may be set much closer together without danger of excessive sparking.

By far the greatest amount of trouble experienced due to sparking at contact points is that encountered in the operation of transmitters and pole-changers used in duplex and quadruplex telegraphy.

In the case of a pole-changer, the negative terminal of a 375-volt dynamo may be connected to the armature front-stop, while the positive terminal of another 375-volt dynamo may be connected to the armature back-stop of the instrument, and as the armature lever (which is connected to the main line via the windings of the line relay) plays between these contact points, there is an ever present danger of arcing, due to the difference of potential (amounting to 750 volts), existing between the front- and back-stops separated by the air-gap traversed by the lever in its movements to and fro.

When an arc forms between the opposite contacts, the great heat developed quickly destroys the metal points and renders them unfit for use. Pole-changers and hand-operated keys which are directly connected into main-line circuits usually have contact points constructed wholly of, or tipped with platinum.

Platinum is the heaviest and least expansible of the metals, is harder than iron, very ductile, undergoes no alteration in air, and resists the action of acids.

Silver also[1] has been used to a considerable extent in making contact points, and while it is true that silver undergoes changes in air, it is claimed that the oxide of silver formed on the exposed surfaces is a better conductor of electricity than the silver itself and that the same necessity does not exist for maintaining clean bright surfaces of contact as is the case with other metals.

It is probable, however, that in cases where the oxide of silver film is allowed to exceed minute thickness, there is danger of the accumulation of foreign matter of low conductivity in association with the somewhat irregular deposit of oxide. This means that where silver contact points are employed, it is the part of wisdom to clean the points with a fine steel file, usually provided for the purpose, as is customary with platinum contacts.

When it is remembered that in the operation of transmitters and pole-changers, the duration of contact between the armature lever (the line) and the stationary contact points (the main-line battery) is very brief, if the full voltage of the dynamo is to be impressed upon the line at each contact, it would seem to be important that the abutting contacts should be free of foreign matter, have smooth regular surfaces, and that the area of surface contact should be such that no appreciable resistance will be introduced at the instant connection is made.

[1] Quite recently wrought tungsten has been introduced as a substitute for platinum in the manufacture of electrical make and break contacts.

It is found in practice that contact points having even regular surfaces and which are kept well polished, do the work required of them more satisfactorily and cause less trouble from sparking than points which are neglected in these respects.

Quite a number of meritorious arrangements have been proposed, having in view the prevention of, or the control of sparking at contact points, several of which methods are described in what follows.

The Postal Telegraph-Cable Company has recently adopted a type of pole-changer which is equipped with a permanent magnet taking the place of the retractile spring formerly used to draw the armature tongue into contact with the back-stop when the magnet coils of the instrument are de-energized.

With a spring retractile, when the local key circuit is closed and the pole-changer coils energized, the pull against the forward movement of the armature increases as the armature moves toward the front-stop, and in the reverse movement of the armature the pull is greatest at the instant the

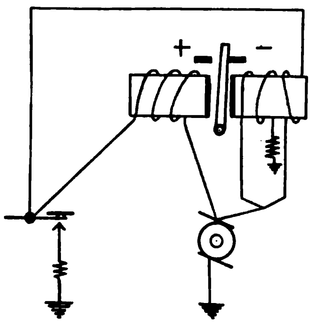


FIG. 243.—Form of pole changer in which the forward and backward movements of the armature are controlled by electro-magnets.

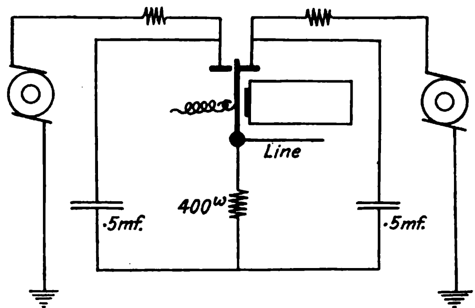


FIG. 244.—Spark-controlling arrangement formerly used by the Postal Telegraph Company.

local key circuit is opened, the strength of pull decreasing as the armature travels toward the back-stop. When a permanent magnet is employed for the purpose, the retractile pull against the armature rapidly decreases as the armature moves toward the front-stop, and rapidly increases as the armature moves toward the back-stop. It is believed that where the permanent magnet is employed, it is possible to maintain a retractile pull more nearly equivalent to that of the forward pull produced by the electromagnets, thus insuring an equal speed of armature travel in either direction. As in the case of the spring retractile, it is necessary that the permanent magnet be so mounted that it may be adjusted with respect to its proximity to the armature, so that ageing of the permanent magnet may be compensated for, and that the retractile force exerted may be made to equal that of the electromagnets under any given conditions of current strength.

One decided advantage of the permanent-magnet retractile is that the "pull" is constant, thus preventing any tendency the armature lever may have to rebound from either back or front contact point. Where the spring is used it is claimed that the reflex action progressing while the coils of the spring are in motion, produces a rebounding movement of the lever which results in sending to line a current impulse somewhat wavy in form.

The type of pole-changer illustrated in Fig. 243 is so designed with regard to the disposition of electromagnets on either side of the armature that when it is desired to have the lever move into contact with, say the positive pole of the battery, the electromagnetic force holding the lever against the opposite battery contact is instantly neutralized, thus the armature is permitted to move in the desired direction without being restrained by an opposing force.

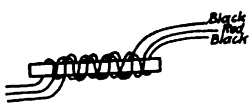


FIG. 245.

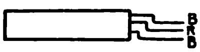


FIG. 245*a*.

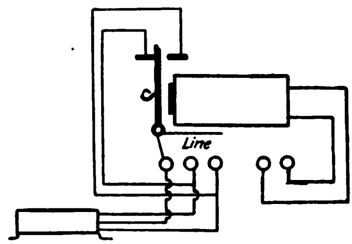


FIG. 245*b*.

FIGS. 245, 245*a* and 245*b*.—Johnson coil spark curbing arrangement.

And conversely when it is desired that the lever shall move into contact with the negative battery pole, the armature again moves in the desired direction without being restrained by an opposing force.[1]

It will be observed that there are no springs or permanent magnets employed in the operation of this instrument. The electromagnet on the right has two equal windings connected differentially, while the magnet on the left has an ordinary single winding.

With the highest speed possible with any type of pole-changer where the armature must start from a position of rest, contact is broken at a relatively low velocity, and as a consequence a considerable amount of sparking takes place.

Various combinations of resistance coils and condensers have been employed successfully in limiting the amount of spark formed at contact points. The arrangement illustrated in Fig. 244 was for a time used by the Postal Telegraph-Cable Company, in connection with pole-changers operating in multiplex circuits. It will be seen that while the armature lever makes and breaks contact with the individual dynamo terminals in the

[1] This is aside from the natural opposition to movement, due to gravity, to inertia, and to bearing friction.

usual manner, a condenser discharge path is at all times maintained around the contact points, the armature being connected to the middle of the discharge circuit by way of a 400-ohm resistance coil, wound non-inductively.

The above arrangement was displaced on the lines of the Postal Company by a form of induction coil known as the "Johnson" coil, see Figs. 245, 245*a* and 245*b*.

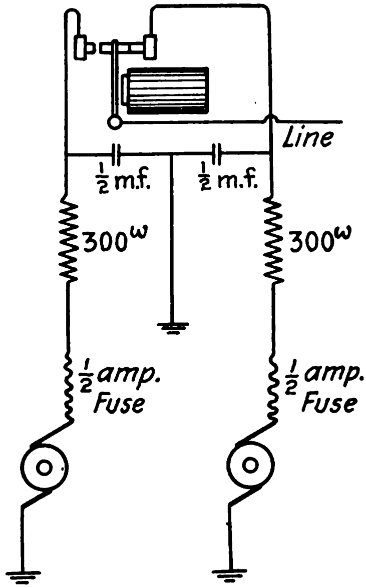


FIG. 246.—Present method of spark control used by the Postal Company.

This arrangement consists of three separate windings of german silver wire of small gage, wound on a wood bobbin with an air core, the spool thus formed being about 7 in. long and 1 in. in diameter. The coils, although wound one on top of the other, are thoroughly insulated from each other by a double cotton covering saturated with paraffine. As indicated in Fig. 245, one end of each winding is left open, while the opposite ends of the windings are connected to the battery contact points and the armature of the pole-changer as depicted in Fig. 245*b*, the center winding (provided with a red covering to distinguish it from the top and bottom windings) being connected with the armature, while the top and bottom windings are connected with the positive and negative battery terminals of the pole-changer.

The inductive action that takes place between the contiguous windings has the effect of absorbing and dissipating the energy of the spark. In cases where the tendency toward sparking is excessive it is helpful to connect two of these "coils" in parallel, similarly to the way in which two condensers are connected in parallel.

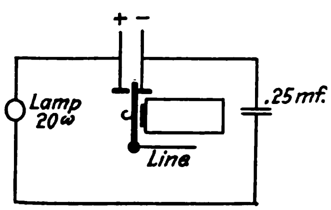


FIG. 247.—Present method of spark control used by the Western Union Company.

Recently the Postal Telegraph Company has adopted the spark-killing arrangement shown in Fig. 246, in which each battery terminal of the pole-changer is provided with a discharge path to ground through a one-half microfarad condenser.

The arrangement used by the Western Union Telegraph Company to limit sparking at pole-changer contact points is illustrated in Fig. 247, in which a 1/4-m.f. condenser connected in series with a 20-ohm lamp of the

incandescent pattern is placed across the battery terminals of the pole-changer.

THE "MAKE" SPARK

It has been stated that the spark which occurs at the instant contact is broken, is due to the extra current of self-induction of the circuit. It might here be stated that the spark which occurs between the armature contact and the battery terminal of a pole-changer at the instant contact is "made" is due to the static discharge from the main and artificial lines, which takes place during the brief instant that actual contact is being made.

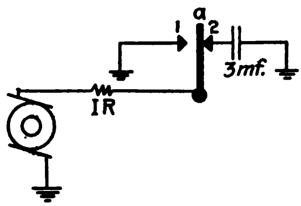


FIG. 248.—Circuit arrangement for demonstrating production of the "make" and the "break" sparks.

By means of a circuit arranged as in Fig. 248, the production of the "make" and of the "break" spark may be observed, and the cause of each determined.

With 2 in contact with *a*, placing 1 also in contact with *a* produces a strong spark at the instant contact is made, while no spark appears as contact between *a* and 1 is broken.

No perceptible sparking takes place as *a* is moved into contact with 1, but at the instant contact is broken between *a* and 1 a pronounced spark appears.

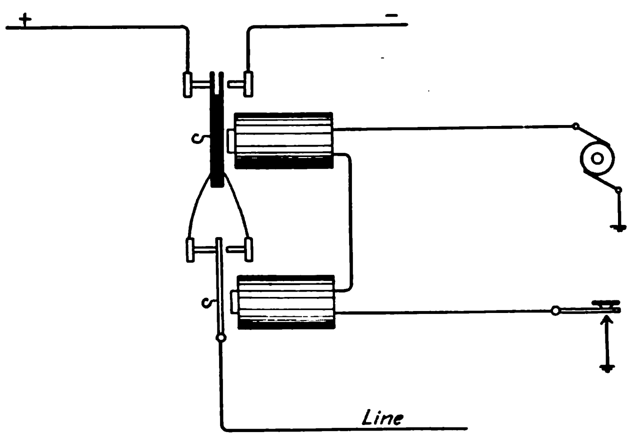


FIG. 249.—Multiple gap and multiple contact pole-changer.

In the first case the "make" spark which develops is due to the discharge of the circuit possessing capacity, and in the second case the spark observed is due to the extra current of self-induction.

It should be remembered, of course, that when arcing takes place between the contact points of a pole-changer, the arc is the result of difference of potential between the battery terminals of the instrument, and that the

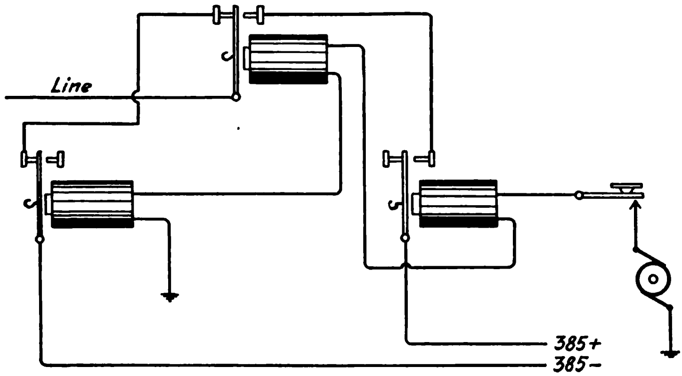


FIG. 250.—Multiple contact pole-changer employing three transmitters.

only part played by the make or the break spark when an arc is "struck" is that of reducing the resistance of the air-gap to a degree which permits the formation of the arc. The heat of the arc which ranges from 2,000 to 5,000° C. is very destructive to the metallic terminals.

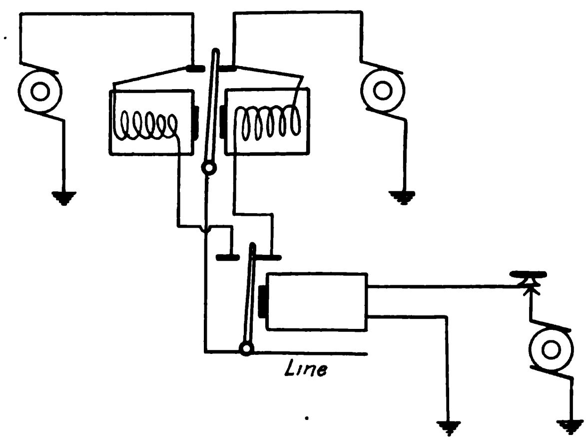


FIG. 251.—The Field multiple-gap pole-changer.

The ordinary make and break sparks, if excessive are liable to heat the air of the gap (thus reducing its electrical resistance) to a point where arcing is likely to occur.

In place of the shunt discharge path, a plan has been tried which consists of providing a multiple gap as illustrated in Fig. 249, wherein it may be

noted that each dynamo terminal is brought to two separate contact points. The armatures of two separate pole-changers are controlled by an individual battery and key circuit, which when closed places both armature levers in contact with the negative pole of the battery and when opened places both levers in contact with the positive pole of the battery. An instrument designed on this principle is known as the Berry pole-changer, being the invention of Mr. T. H. Berry.

It is evident that as each battery contact is made at two separate points, the sparking tendency at each contact is halved.

A similar arrangement employing three ordinary pole-changers for the purpose is illustrated in Fig. 250.

Figure 251 shows a pole-changer having a multiple gap, which has been designed by Mr. Stephen D. Field.

In cases where high potentials are employed, and where high signaling speeds are not essential, the "oil" break has been used with success. With this arrangement the pole-changer is inverted and the contact between armature and battery terminals is made to take place in a chamber filled with thin oil, in which case the oil serves to extinguish the spark as soon as formed.

CHAPTER XIV

THE QUADRUPLEX

THE JONES SYSTEM. THE FIELD KEY SYSTEM. THE POSTAL QUADRUPLEX. THE SINGLE DYNAMO QUADRUPLEX. THE METALLIC-CIRCUIT QUADRUPLEX. THE GERRITT SMITH QUADRUPLEX. THE WESTERN UNION QUADRUPLEX. THE B.P.O. QUADRUPLEX.

Quadruplex telegraphy consists of a method of sending two messages simultaneously over an individual wire in one direction, while at the same time two additional messages are being transmitted over the same wire in the opposite direction.

A wire equipped at each end with quadruplex apparatus may be used to transmit one, two, three, or four telegrams at the same time. That is, when the wire is equipped for quadruplex working, one message at a time may be sent over it, or, if required, four telegrams (two in each direction) may be transmitted simultaneously.

The system of quadruplex telegraphy generally employed is based on a combination of the Stearns, or single-current duplex, and the differential polar duplex, both of which have been described in the preceding chapter.

One message in each direction may be transmitted by means of the single-current half of the system due to changes effected in the strength of the line currents without regard to the polarity of said currents, while one message in each direction may at the same time be transmitted by means of the polar half of the system due to alterations in the polarity of currents impressed upon the line, which alterations are effected through the agency of ordinary transmitting keys and pole-changers as described in connection with the differential polar duplex system.

Figure 252 shows the theoretical wiring of the main-line circuits, and the pole-changer and transmitter local circuits of a quadruplex arranged to operate with gravity battery. In the diagram the circuit arrangements at two terminal stations are shown, the two stations *X* and *Y* being connected by a line wire.

For the sake of clearness the reading sounder circuits which are operated locally through the action of the armatures of the polar relays and the neutral relays have been omitted. The letters *o* and *c*, however, are used as indices to denote the open and the closed positions of the respective relay armatures. In each case the closed position of the relay armature implies that the signaling armature lever of the reading sounder connected thereto would also be in the closed or marking position.

It is to be remembered that the armature of the polar relay will be drawn into the closed position when current traverses the coil windings of the relay in a given direction, and into the open position when current travels through the coils in the reverse direction. It is immaterial whether the respective currents are weak or strong. A weak negative current, for instance, will

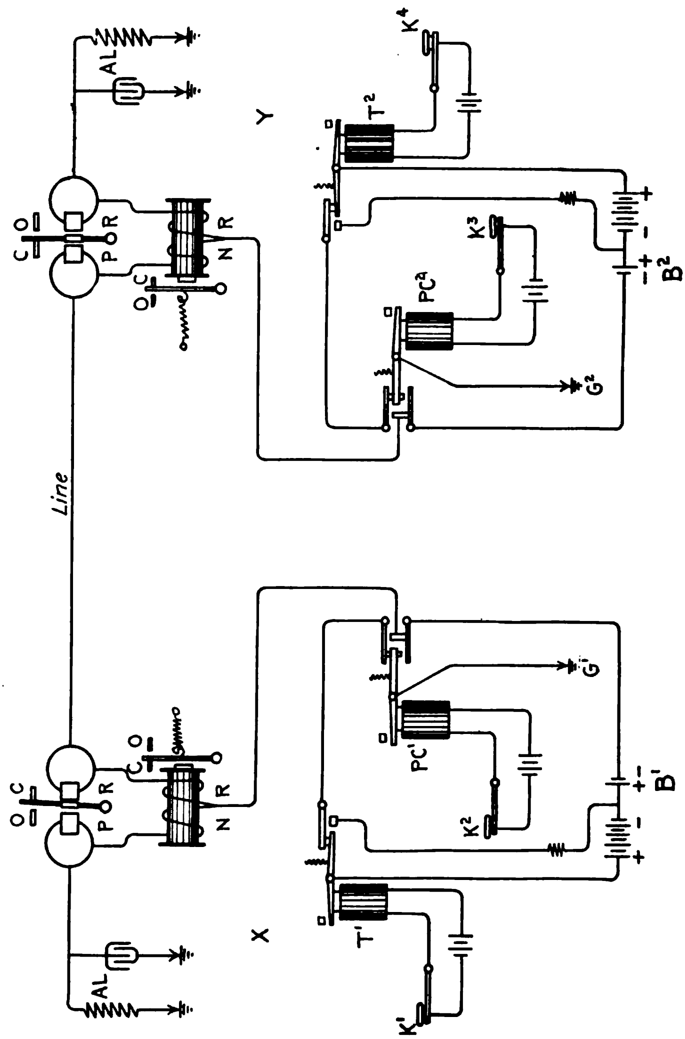


Fig. 252.—Theory of the quadruplex, using gravity battery and continuity preserving transmitters.

cause the armature to move in one direction, while a weak positive current will cause the armature to move in the opposite direction.

Polar relays work satisfactorily with currents varying from 3 milliamperes to 200 milliamperes, which means that although the movement of the armature in one direction may be the result of a strong positive impulse, the armature

may be moved in the opposite direction by a weak negative impulse, provided, of course, that the positive current has been disconnected or suppressed. Also, it will at once be apparent that should a wire carrying a current of, say, 50 milliamperes from a positive source be connected to one terminal of the coil winding of the relay, while a wire carrying a current of 55 milliamperes from a negative source is connected to the other terminal, the surplus of 5 milliamperes negative current would be sufficient to move the armature in the direction which a negative current of any strength would move it. Further, as stated in connection with the operation of the relay used in the polar duplex, the armature tongue of the relay, due to the attraction of the permanent magnets associated therewith, remains in connection with the open or the closed contact once it has been moved there, until the direction of the current through the coils of the instrument has been reversed, whereupon the tongue instantly moves over to the opposite contact.

That half of the quadruplex which is operated by means of current reversals is called the polar, *A*, or first side of the system, while the half which is operated by raising and lowering the strength of the current obtaining in the main-line circuit is called the neutral, common, *B*, or second side of the system.

THE DIFFERENTIAL NEUTRAL RELAY

The description of the differential relay given on page 251 applies equally to the type of relay employed on the second side of the differential quadruplex to record the signals transmitted from the distant station as a result of the operation of the transmitter connected into the line at that point, and by means of which the strength of current permitted to traverse the line is regulated.

The forward and backward movements of the armature of the neutral relay are accomplished in a manner somewhat different from that which actuates the armature of the polar relay. The armature tongue of the neutral relay is drawn into contact with its back-stop by the action of a retractile spring which may be given a tension such that a comparatively large volume of current must traverse one or both coils of the relay before the armature will be attracted forward. Also, as is the case with the ordinary or common single Morse relay, it is immaterial whether the current traversing the coil windings of the relay is from a positive or a negative source, provided the current actuating the magnets has the required strength to overcome the spring tension which tends to hold the armature tongue against its back-stop.

Thus it is seen that if the current operating the polar side of the system is kept down to a strength of, say, 25 milliamperes, the retractile spring of the companion neutral relay may be given a tension which will prevent it from responding to currents of such comparatively low volume.

It is customary to so adjust the neutral relay that a current strength three times, or four times, greater than that which operates the polar relay must be impressed upon the line before the neutral relay will respond. As long, therefore, as the neutral side transmitter at the distant station is not operated, and while minimum current value obtains in the main-line circuit, although the polar side may be operated, the neutral relay remains unresponsive. The instant, however, that the neutral side transmitter at the distant station is closed, maximum current value obtains in the main-line circuit and the neutral relay at the home station instantly responds.

The various electrical actions which take place when full quadruplex operation is maintained over a wire are directly dependent upon the difference of potential existing between certain points in the main-line circuit

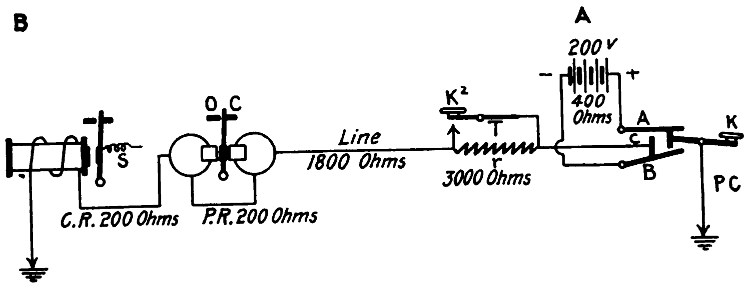


FIG. 253 —The Diplex.

within the apparatus at each end of the line, upon the resistance of instrument windings and accessory resistance units, and upon the direction and strength of currents flowing through relay windings at certain instants and under certain conditions.

Most students find it difficult to carry in their minds a picture of the many operations taking place which, taken all together, constitute quadruplex working. But, if the subject is approached with a view to mastering each detail of operation separately, it is found generally that when the various details are understood, the theory of the system as a whole will be more firmly impressed upon the mind than if this method of study were not followed.

We have seen in the case of the Stearns duplex, the polar duplex and the bridge duplex, that two messages at a time may be sent over a single wire, one in each direction. In order to maintain quadruplex operation, means must be provided for transmitting four messages at a time over a single wire, two in each direction.

It will be helpful; first to consider an arrangement such as that illustrated in Fig. 253, by means of which it is possible to transmit two messages simultaneously over a single wire, both in one direction. This provides what was at one time known as diplex operation.

As transmission is carried on in one direction only, one station is equipped

with sending apparatus, while the other station is equipped with receiving apparatus only.

The particular arrangement of circuits depicted in Fig. 253 is submitted here; not that it closely resembles the circuit arrangements comprising the diplex system of telegraphy originally introduced, but because it embodies features common to the present-day system of quadruplex telegraphy which make possible the simultaneous transmission of two messages in each direction over a single wire.

A line wire having an assumed resistance of 1,800 ohms is shown extending between stations *A* and *B*, the direction of transmission being from *A* to *B*. The main battery consisting of gravity cells, having a total e.m.f. of 200 volts and an internal resistance of 400 ohms is located at *A*, as also is the pole-changer *PC*, operated locally by means of a key *K*, and the transmitter *T*, the latter in this case consisting simply of a key K_2 which, when open places the 3,000-ohm shunt coil *r* in series with the line wire, and when closed short circuits this coil.

At the receiving end of the line two relays are connected directly into the main-line circuit as shown. One of these—the polar relay *PR*—is actuated by current reversals, that is, its armature is moved into the closed position when the negative terminal of the distant battery is placed to line, and into the open position when the positive terminal, or pole, of the distant battery is placed to line.

The operation of the common relay *CR* is dependent upon the strength of the current traversing its coils, and not upon the direction of current.

By referring to the diagram it may be seen that at the sending station the key *K* is depressed. This action has moved the spring contact *A* away from the line contact-block *c*, with the result that the positive terminal of the battery is connected to ground via the key *K*, while the negative terminal of the battery is placed to line by way of spring contact *B* and line contact-block *c*, from which point the main-line circuit to ground at the distant station is made up via the 3,000-ohm coil *r* (Key K_2 now being open) the 1,800-ohm line wire through the windings of the polar relay and the common relay, thence to ground.

Calculation will show that the current strength obtaining in the circuit is about 36 milliamperes. And if it is assumed that the spring *S* attached to the armature of the common relay has been given a tension such that a current strength considerably in excess of 36 milliamperes must obtain in the circuit before the armature of the relay is attracted, it is plain that the operation of the pole-changer at the sending station will have no effect upon the common relay, while on the other hand, the armature of the polar relay is moved into the closed position each time a negative current is sent to line, and into the open position each time a positive current is sent to line from the

distant station. It must be kept in mind, as pointed out elsewhere, that the polar relay responds to very low current strengths.

Now, if key K_2 is depressed, thus short circuiting the 3,000-ohm coil r, a strength of current will obtain in the circuit which is about three times greater than that which existed while the key K_2 remained open.

It is self-evident, therefore, that the operation of the key K_2 controls the movements of the armature of the common relay, while the operation of the key K controls the operation of the polar relay.

DOUBLE TRANSMISSION IN BOTH DIRECTIONS

Having an apparatus such as the diplex by means of which two sets of signals may be sent in the same direction over a single conductor without interference with each other, it is evident that by employing differentially wound relays at each end of the line, placing one winding of each relay in the main-line circuit while the other winding of each relay is included in the artificial-line circuit, as is done in the case of the Stearns and polar duplexes, it is possible to transmit two messages in each direction simultaneously.

THE GRAVITY BATTERY QUADRUPLEX

Figure 254 shows theoretically the main-line circuits of a quadruplex operated with current derived from a gravity battery. The type of pole-changer shown here is different from that illustrated in connection with Fig.

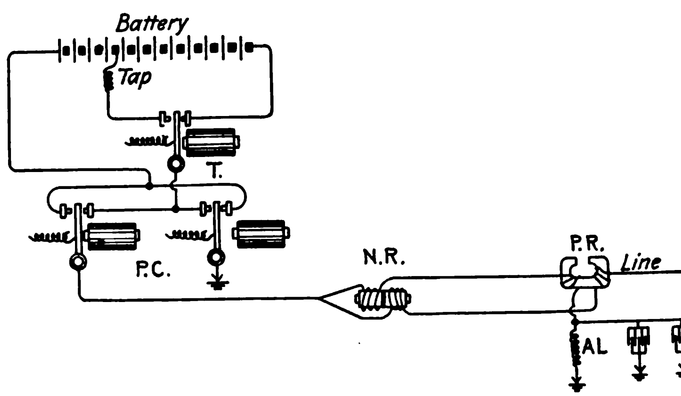


FIG. 254.—Postal Telegraph Company's gravity battery quadruplex. Theory.

252 (see also Fig. 255) and consists of two double-contact relays of the usual construction.

In practice an individual sending key connected through a local battery controls the operation of both of the instruments comprising the pole-changer. By this means, when the key is depressed both armatures of the pole-changer

relays are attracted into contact with their front-stops, and when the key is opened both armatures are withdrawn into contact with their back-stops, due to the tension of the retractile springs attached to them for that purpose.

It may be noted that the function of the armature of the instrument on the right is to "ground" either pole of the main battery, while the function of the armature of the instrument on the left is to place to line that pole of the battery which is not grounded. The pole of the battery which is grounded and the pole which is to line at any given instant depends upon the positions of the respective armatures. When the signaling key is closed, both armature tongues will be in contact with their front-stops. In the case before us this action has placed the negative pole of the battery to the line, while the positive pole of the battery is grounded. On the other hand,

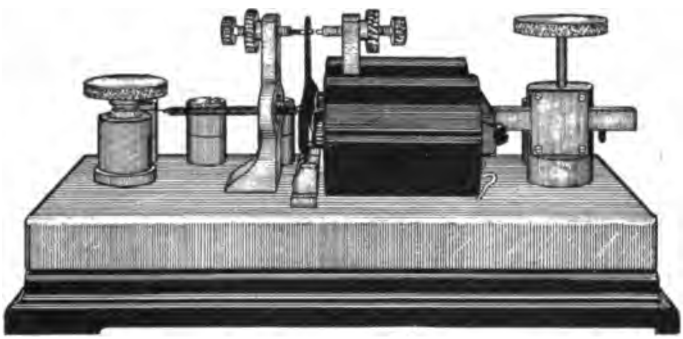


FIG. 255.—Pole-changer or transmitter. Postal pattern.

when the signaling key is opened, the positive terminal of the battery will be placed to line while the negative pole will be grounded. Thus, it is seen that the operation of the signaling key controlling individually the movements of the two armatures results in currents being sent to line which alternate in polarity.

THE TRANSMITTER

The position of the armature of the transmitter T, at any given instant determines whether the whole or a portion only of the main battery is utilized. By observing the two possible positions of the transmitter armature it will be evident that when the signaling key which controls the operation of the transmitter is depressed, the armature tongue will be moved into contact with its front-stop thereby opening the "tap" connection and placing the entire battery in service. When, on the other hand, the key is opened and the armature tongue is withdrawn into contact with its back-stop, one-third or one-fourth, as the case may be, of the main battery is availed of.

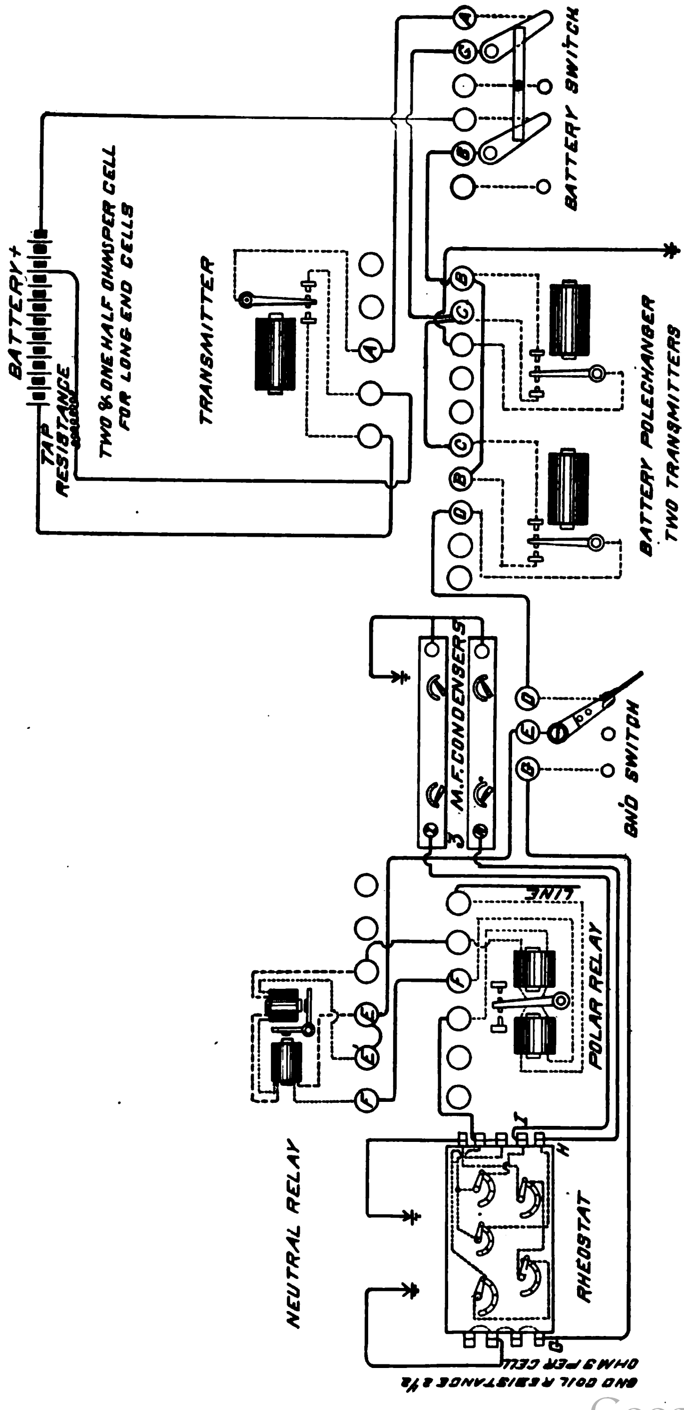


FIG. 256.—Actual connections of the gravity battery quadruplex as used by the Postal Telegraph Company.

LONG END AND SHORT END

When the armature of the transmitter is in the position which places the entire battery in service, it is said that the long end is to line, and when the armature of the transmitter is in the opposite position, that is, when a part of the battery is utilized, it is said that the short end of the battery is to line.

Figure 256 shows the actual binding-post main-line connections of a battery quadruplex, the theoretical wiring of which is shown in Fig. 254. In the actual instrument connections the artificial line is made up of an adjustable rheostat and two 3-m.f. condensers, the latter also being adjustable.

THE DYNAMO QUADRUPLEX

THE JONES SYSTEM

The distinguishing feature of the Jones dynamo quadruplex is the method employed to furnish the long-end and the short-end main-line potentials. By referring to diagram 257, it may be seen that four separate dynamos are required to furnish the desired potentials—two 130-volt machines and two 385-volt machines. The 130 volts plus and minus serving as the reduced potential, while the higher voltage serves as the full potential to operate the neutral relay at the distant end of the line.

In the diagram the polar-side transmitting key K_1 is shown in the closed position, the result of which is that the armature levers of the two instruments comprising the pole-changer are in contact with their front-stops. This in turn connects the 130-volt negative potential and the 385-volt negative potential with the back-stop and front-stop respectively of the transmitter T. It is plain then, that as long as the key K_1 is kept closed, closing key K_2 sends to line full current strength, while opening key K_2 thereby placing the armature of the transmitter in contact with its back-stop sends to line a current of a strength approximately one-third of that sent out when the transmitter armature is in the closed position.

Where the booster arrangement (see Fig. 45, page 63) for supplying quadruplex potentials is installed, the Jones quadruplex system may be employed to advantage.

THE FIELD KEY SYSTEM[1]

With the Jones quadruplex it is necessary to employ two different e.m.fs., one to operate the polar and one to operate the neutral side of the system.

[1] The first practical application of the dynamo as a substitute for the chemical battery in the operation of telegraph lines was made in the year 1879 by Mr. Stephen D. Field, then of San Francisco. (See U. S. patents, Nos. 223,845, Jan. 27, 1880, and 243,698, July 5, 1881.)

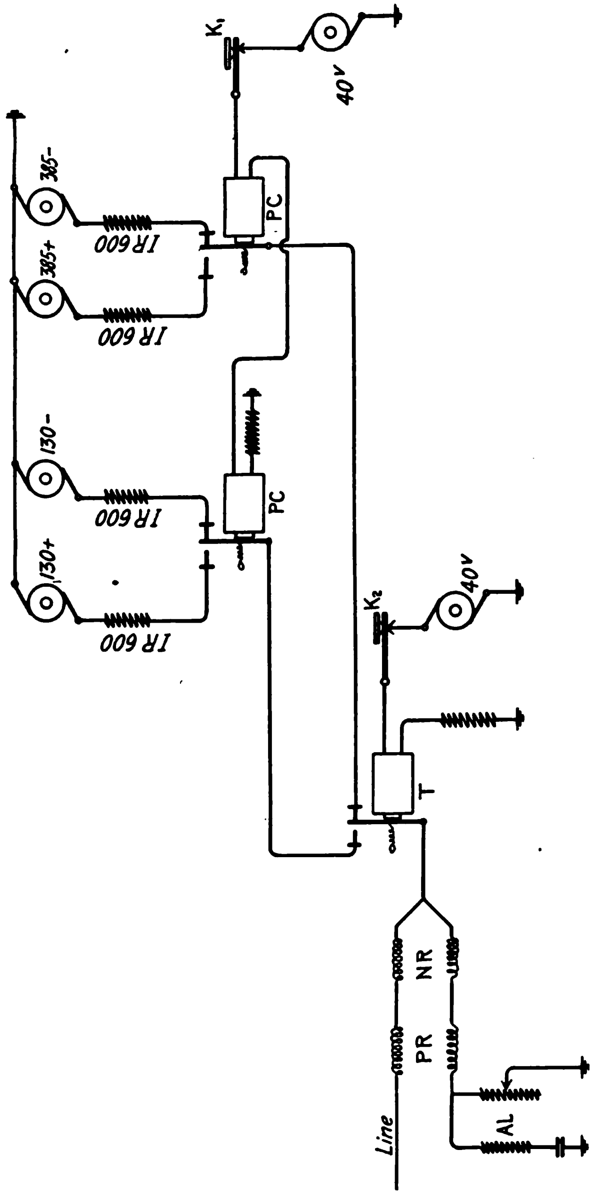


FIG. 257.—Jones dynamo quadruplex system.

As the current strength required to operate the latter compared with that required to operate the polar side is in ratio 3 to 1, or 4 to 1, as the case may be, it is evident that with the Jones system four sources of e.m.f. are required, two of the higher value, one being negative and the other positive, and two of the lower value, negative and positive. It is, of course, understood that while four dynamos are required to operate one quadruplex, the same four machines may at the same time be employed to supply current for a number of similar quadruplex circuits.

Where the Field quadruplex system is employed the number of dynamos required is reduced one-half, as two machines only are needed, one delivering positive and the other negative current. Each dynamo delivers an e.m.f. of sufficient strength to operate the neutral side, and by employing properly proportioned resistances the insertion of which is automatically controlled by operating the transmitting key associated with the second side, the potential may be reduced to a value suitable to operate the polar side of the system.

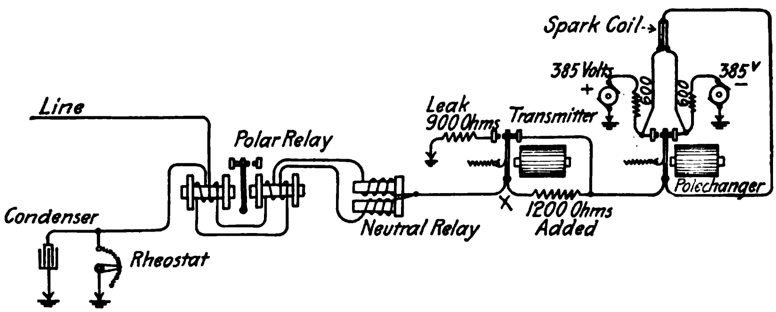


FIG. 258.—Theory of the Field quadruplex.

In this manner is produced what has heretofore been referred to as the "long end" and the "short end."

The ratio of "long-end" to "short-end" e.m.f. determines the ratio of maximum to minimum line current, and the novelty of the Field key quadruplex, is in the arrangement of voltage-reducing resistances which not only provide for the sending out of the two properly proportioned current strengths, but at the same time insure that the whole or joint-resistance of the terminal circuits remains the same regardless of the position of the armature of the transmitter controlling the strength of currents sent to line.

Figure 258 shows the theoretical main-line wiring of the Field quadruplex. With the armatures of the pole-changer and the transmitter in the positions shown in the diagram, the completed circuit extends from the 385-volt -dynamo to the closed-contact of the pole-changer, thence via the armature of the pole-changer along a short connecting wire to the closed-contact of the transmitter, from which point the circuit extends—by way of the

armature of the transmitter—to the "split" or joint-circuit made up through the differential windings of the two relays, half of the current reaching the earth via one winding of each relay and the artificial-line rheostat, while the other half reaches the earth at the distant station via the companion windings of the relays, the line wire, and the distant end apparatus, that is, the current divides equally when the resistance of the rheostat is made to equal the resistance of the line wire plus the resistance of the terminal apparatus at the distant station.

It is apparent, owing to the shunt circuit established around the 1,200-ohm added resistance by the transmitter armature, that the only appreciable resistance inserted before the differential circuit is reached is that of the internal resistance unit (in this case having a value of 600 ohms) connected into the battery lead between the dynamo and the pole-changer, and which serves to protect the machine in case of accidental short-circuit.

It is evident, too, with the armatures of the pole-changer and the transmitter in the positions shown, that the nearest ground contact is at the distant station and at the end of the home artificial-line rheostat circuit, each ground being equally distant ohmically when the resistance of the artificial-line circuit is made to equal the resistance of the circuit to ground at the distant station.

As long, therefore, as the transmitter armature remains in the closed position the full potential of the dynamo is impressed upon the line, and the operation of the pole-changer results in positive and negative currents of maximum strength being sent to line as the armature tongue of the pole-changer is moved into contact with the open or closed contact respectively.

Assume now that the key circuit controlling the operation of the transmitter is opened, permitting the retractile spring to withdraw the armature into contact with its back-stop, it will be seen that the nearest ground contact is distant in ohms from the source of e.m.f. 600 ohms (internal), plus 1,200 ohms (added), plus 900 ohms (leak), or 2,700 ohms; and further, that the point X is two-thirds of the distance (ohmically) to the nearest ground, for, 600 plus 1,200 is two-thirds of 2,700. This means that at the point X, while the transmitter armature tongue is in contact with its back-stop, the voltage has dropped from 385 to one-third of 385, or omitting fractions, 128 volts.[1]

With these particular values of added and leak resistances we have a ratio of 3 to 1, with a long-end potential of 385 volts and a short-end potential of 128 volts, the former being impressed on the line when the armature tongue of the transmitter is in contact with its front-stop, and the latter when the tongue is in contact with its back-stop. This in turn insures that maximum current will obtain in the main-line circuit while the signal-

[1] See Fall of Potential in an Electric Circuit, page 88.

ing key which controls the operation of the transmitter is closed, and that minimum current will obtain in the main-line circuit while the same key is open. The result, therefore, is that closing the transmitter key[1] causes a current volume in the main-line circuit of sufficient strength to attract the armature of the neutral, or common-side relay at the distant station, while opening the transmitter key circuit results in the main-line current strength being so reduced that the armature of the distant neutral relay is withdrawn from the closed position due to the tension of the retractile spring attached to it.

So far as the operation of the neutral relay at the distant station is concerned it is immaterial whether the armature of the home pole-changer is in contact with the +385-volt dynamo or the −385-volt dynamo, as the neutral relay responds to either polarity, provided maximum current strength obtains in the main-line circuit.

The operation of the polar relay at the distant station being dependent upon current reversals, regardless of the strength of the current, is as a consequence under the control of the home pole-changer. As long as the armature tongue of the home pole-changer remains in contact with the negative battery connection, the armature of the polar relay at the distant office will be in one position, and as long as the armature of the pole-changer is in contact with the positive battery connection the armature of the distant polar relay will remain in the opposite position.

METHOD OF DETERMINING THE REQUIRED OHMIC VALUE OF RESISTANCE COILS TO USE IN THE FIELD KEY SYSTEM TO OBTAIN ANY DESIRED PROPORTION

Instead of a current ratio of 3 to 1, it is sometimes advisable to maintain a ratio of 3 1/2 to 1, or 4 to 1, etc.

Convenient and simple formulæ for determining the values of the added and leak resistances for any given ratio are given herewith,

where R, represents ratio,
B, represents internal resistance,
R_1, represents added resistance,
R_2, represents leak resistance,

then
$$R_2=\frac{BR}{R-1},$$

or
$$R_2=\frac{B+R_1}{2}$$

$$R_1=B\ (R-1)$$

$$R=\frac{B+R_1+R_2}{R_2}$$

[1] For the sake of clearness the transmitter local key circuit has been omitted.

The value of the internal resistance is usually selected with regard to the measure of protection to be given the generators, and in practice may be 600, 300, 200, 100 ohms, or less.

Suppose, for instance, that with an internal resistance of 600 ohms a certain circuit is to be operated on a 3 to 1 basis:

R, has a value of 3,
B, a value of 600, then

$$\text{added resistance} = 600 \times (3-1) = 1{,}200 \text{ ohms}$$

$$\text{leak resistance} = \frac{600 \times 3}{3-1} = 900 \text{ ohms, or the same as the}$$

values indicated in Fig. 258.

When the values of the internal, leak, and added resistances are known, the ratio, according to the formula, would be

$$\frac{600+900+1200}{900} = 3$$

To ascertain the value of the potential at the point X (Fig. 258) with any given combination of added resistance, the following formula applies:

$$X = \frac{E\ (R - R_1)}{R}$$

where E represents the voltage of the generator,
R represents the resistance of the whole circuit to the nearest ground,
R_1 represents the point distant in ohms from the source of e.m.f.

With the resistance values shown in Fig. 258,

$$X = \frac{385 \times 900}{2700} = 128\ 1/3 \text{ volts.}$$

By the aid of the foregoing formulæ, the subjoined table has been compiled showing the added and leak resistance values required with ratios of 3–1, 3.5–1, and 4–1, with internal resistance values ranging from 50 to 1,000 ohms.

ADDED AND LEAK RESISTANCE

Internal resistance	3 to 1		3.5 to 1		4 to 1	
	Added	Leak	Added	Leak	Added	Leak
50	100	75	125	70	150	67
100	200	150	250	140	300	133
200	400	300	500	280	600	267
300	600	450	750	420	900	400
400	800	600	1,000	560	1,200	533
500	1,000	750	1,250	700	1,500	667
600	1,200	900	1,500	840	1,800	800
700	1,400	1,050	1,750	980	2,100	933
800	1,600	1,200	2,000	1,120	2,400	1,067
900	1,800	1,350	2,250	1,260	2,700	1,200
1,000	2,000	1,500	2,500	1,400	3,000	1,333

TERMINAL RESISTANCE

It is necessary that the whole or joint-resistance of the terminal apparatus remain the same regardless of the position of the armature of the transmitter at any instant. That this is important is evident from the fact that in the act of balancing, the distant station adjusts the resistance of the artificial-line rheostat to equal the resistance of the line plus the resistance of the apparatus at the other end of the line. Therefore, after the balance has been taken the same value should at all times be maintained, else the outgoing currents will not have identical values in the separate windings of the relays.

Figure 259 shows the resistance values of the various elements of a quadruplex set at each end of a line extending between stations *Y* and *Z*, assuming a line conductor resistance of 2,000 ohms, an internal resistance of 600 ohms in each dynamo lead, a long-end potential of 385 volts, and a ratio of long to short e.m.f. of 3 to 1.

It may be observed that the resistance of the terminal apparatus at each station remains the same at all times. With the armatures of the pole-changer and the transmitter in the positions shown in the diagram the only appreciable resistance presented to incoming currents at station *Z* (in addition to the relay resistance) is the 600-ohm internal resistance *B*, as it is plain that the 1,200 ohms added resistance is short circuited by virtue of the closed position of the transmitter armature. Should the pole-changer key be opened so that the armature tongue of the latter is withdrawn into contact with its back-stop there is still presented a 600-ohm path to ground.

Referring now to the conditions prevailing at station *Y*: At first sight it would seem that owing to the armature tongue of the transmitter being in contact with its back-stop, a path is presented to incoming signals which has a resistance considerably higher than that which obtains when the armature is in the closed position, but a little consideration will show that with the transmitter armature in the position shown at *Y* the incoming signals have a joint path from the point *X* consisting of a 900-ohm branch and an 1,800-ohm branch, and calculation will show that the joint-resistance of these two paths is 600 ohms.

RESISTANCE OF THE "GROUND" COIL

When the attendant at one end of the quadruplexed circuit "takes a line balance," that is, when he adjusts the resistance of the artificial line rheostat to equal the resistance of the line and of the apparatus at the distant end of the line, it is necessary that the main-line battery at the distant end of the line be removed until the balance is taken.

Assume that the attendant at *Y* (Fig. 259) is about to take a balance. In the process of balancing, the attendant at *Z* is required to "ground" the line (thereby removing the main-line battery at *Z*) by moving the switch lever *S* into contact with the ground connection. Inasmuch, therefore, as the balance is taken when a 600-ohm terminal resistance is presented at the distant station it is essential that when the switch *S* is turned back to the regular position (thereby placing battery to line) the terminal resistance presented must remain the same, namely, 600 ohms, if the balance is to hold good while the circuit is in operation.

The value of the resistance of the ground coil must be identical with that of the internal resistance *B*, which also is identical with the joint resistance of the terminal resistance presented to incoming signals when the armature of the transmitter is in contact with the leak circuit.

Undoubtedly it will have occurred to the reader that the resistance of the terminal apparatus (600 ohms in this case), in reality forms one branch of a joint circuit, the other branch of which consists of the 3,100-ohm circuit to ground made up via the relay windings and the artificial-line rheostat, and, of course, this is true, for in the case under consideration (Fig. 259) the joint resistance of 600 ohms and 3,100 ohms is approximately 503 ohms, but it is evident that the 3,100-ohm branch of the joint circuit formed a joint circuit with the 600-ohm ground coil at the time the balance was taken, so that the actual total resistance of the terminal apparatus presented to incoming signals is the same regardless of the position of the ground switch.

OPERATION OF THE QUADRUPLEX

If the reader has mastered the principles of operation of the Stearns duplex and of the polar duplex described in Chapter XIII he should have

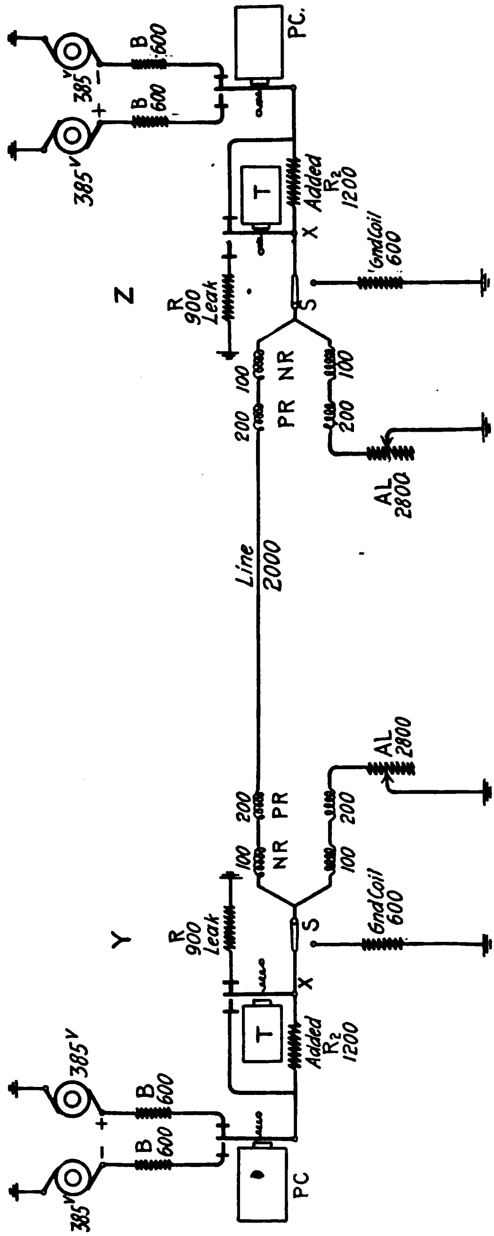


FIG. 259.—Terminal resistance values of the Field quadruplex.

little difficulty tracing out the various operations which take place in the quadruplex while two messages are being transmitted in each direction at the same time. The method of study which gives the best results is for the student to draw diagrams showing the various positions of the transmitter and pole-changer armatures at either end of a quadruplex circuit and from these gain a first hand knowledge of the operation of the relays at each end in response to the operation of the signaling keys at the opposite end of the circuit.

In making up diagrams the following schedule of combinations may be used as a guide in tracing the various possible connections:

1. Home *PC* open, Distant *PC* open, Home *T* open, Distant *T* open.
2. Home *PC* closed, Distant *PC* open, Home *T* open, Distant *T* open.
3. Home *PC* open, Distant *PC* open, Home *T* closed, Distant *T* open.
4. Home *PC* closed, Distant *PC* open, Home *T* closed, Distant *T* open.
5. Home *PC* open, Distant *PC* closed, Home *T* open, Distant *T* open.
6. Home *PC* closed, Distant *PC* closed, Home *T* open, Distant *T* open.
7. Home *PC* open, Distant *PC* closed, Home *T* closed, Distant *T* open.
8. Home *PC* closed, Distant *PC* closed, Home *T* closed, Distant *T* open.
9. Home *PC* open, Distant *PC* open, Home *T* open, Distant *T* closed.
10. Home *PC* closed, Distant *PC* open, Home *T* open, Distant *T* closed.
11. Home *PC* open, Distant *PC* open, Home *T* closed, Distant *T* closed.
12. Home *PC* closed, Distant *PC* open, Home *T* open, Distant *T* closed.
14. Home *PC* closed, Distant *PC* closed, Home *T* open, Distant *T* closed.
15. Home *PC* open, Distant *PC* closed, Home *T* closed, Distant *T* closed.
16. Home *PC* closed, Distant *PC* closed, Home *T* closed, Distant *T* closed.

THE DAVIS-EAVES, OR POSTAL QUAD

The Postal Telegraph-Cable Company has recently put into service a large number of quadruplex sets arranged as shown theoretically in Fig. 260.

It will be recognized that the arrangement constitutes an improved Field quadruplex; the new features consisting of the 500-ohm "bridge" coils, the bridge-condenser circuit, the "timed" condenser circuit around

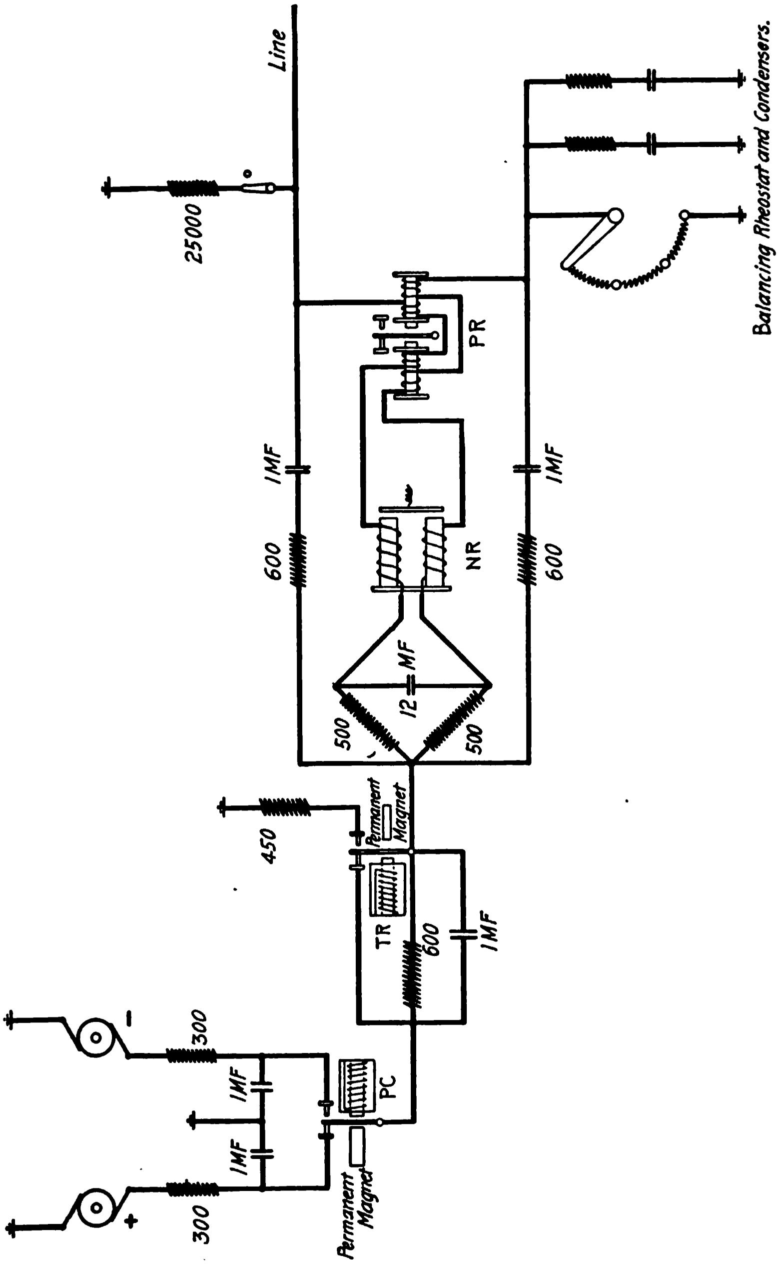


FIG. 260.—Davis-Eaves, or Postal quadruplex. Theory.

the relays, the 25,000-ohm leak circuit from line to ground, also a reduced value of internal, leak, and added resistance.

It will be noted, too, that the spark curbing device consists of two 1-m.f. condensers shunting the pole-changer battery contacts and provided with a discharge path.

The functions of the bridge coils and the condenser circuits have been described in connection with the high-efficiency duplex, Fig. 257, page 296.

Owing to the fact that the terminal resistance of the set has been reduced to 300 ohms in place of the 600 ohms formerly used; that the resistance of the polar relay has been reduced from 300 to 200 ohms, and that of the

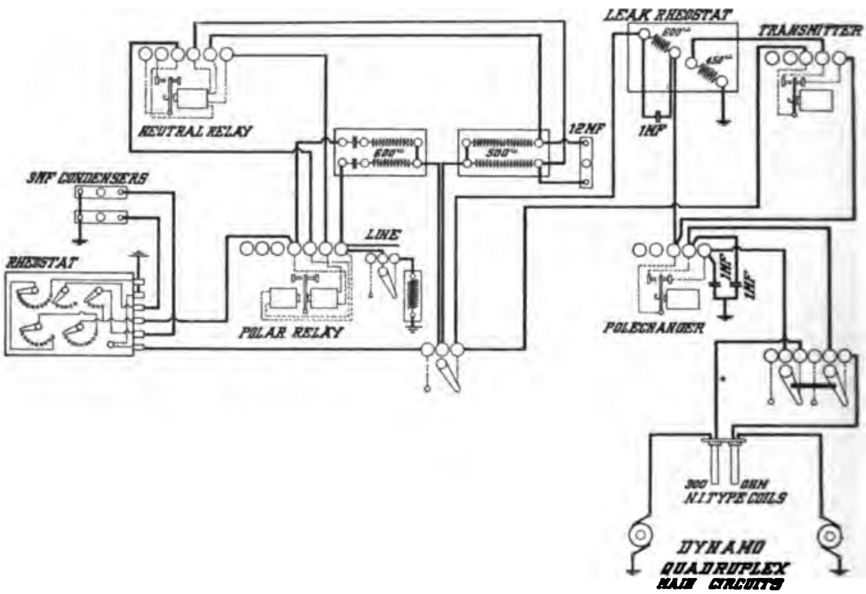


FIG. 261.—Actual connections of the "Postal" quadruplex.

neutral relay from 150 to 60 ohms, the total resistance of the apparatus remains practically the same as that of the Standard Field quadruplex, and inasmuch as specially arranged paths have been provided for induced line disturbances it is not necessary to employ very high potentials to override line currents from extraneous sources, so that in many instances it is possible to reduce the potential from 385 volts to 250 volts, or less, and still maintain satisfactory quadruplex operation.

Figure 261 shows the actual binding-post connections of the Postal quad including all of the new elements referred to above.

SINGLE DYNAMO QUADRUPLEX

Figure 262 is a sketch of the theory of the connections of a single-dynamo quadruplex arranged with a "double-relay" pole-changer so that one dynamo

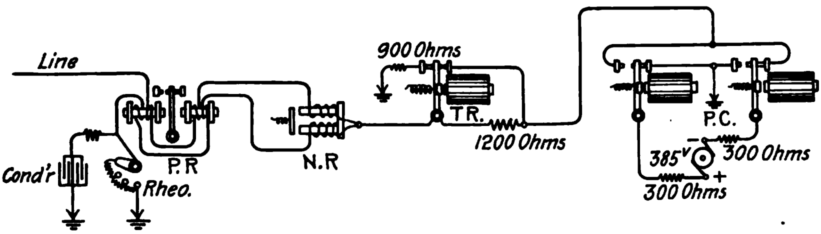


FIG. 262.—Single dynamo quadruplex. Theory.

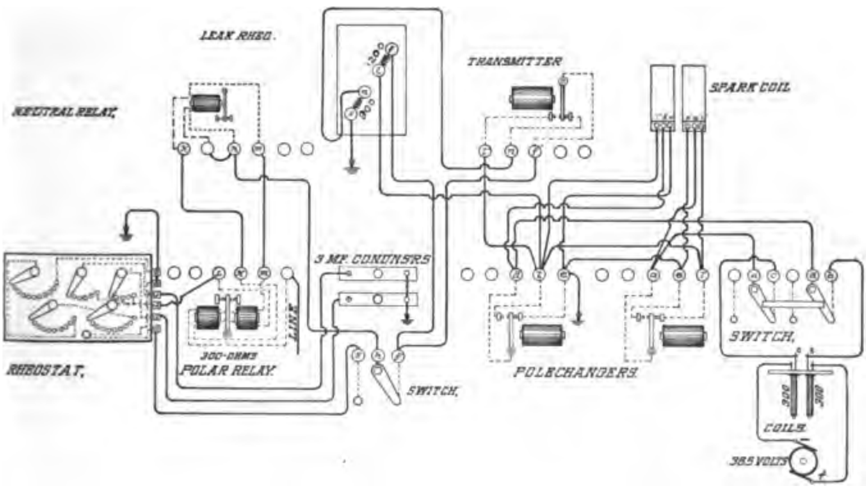


FIG. 263.—Binding-post main line connections of the single dynamo quadruplex.

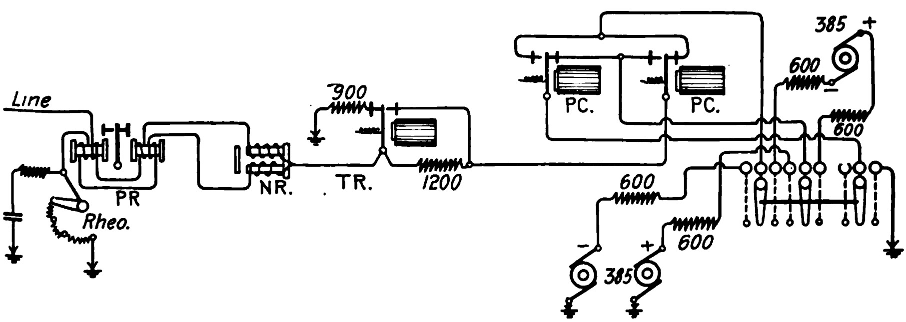


FIG. 264.—Theoretical connections of a set arranged to be used either as a single dynamo quadruplex or as a double dynamo Field quadruplex.

will serve to furnish currents of both polarities, positive and negative, for main-line purposes. It will be noted that when the armatures of the two instruments which comprise the pole-changer, are in contact with their front-stops, the negative terminal of the dynamo is placed to line, while the positive terminal of the dynamo is grounded. And, when the respective armatures are in contact with their back-stops, the positive terminal of the dynamo is to line and the negative terminal grounded. Otherwise the connections of the set are the same as in the standard Field quadruplex.

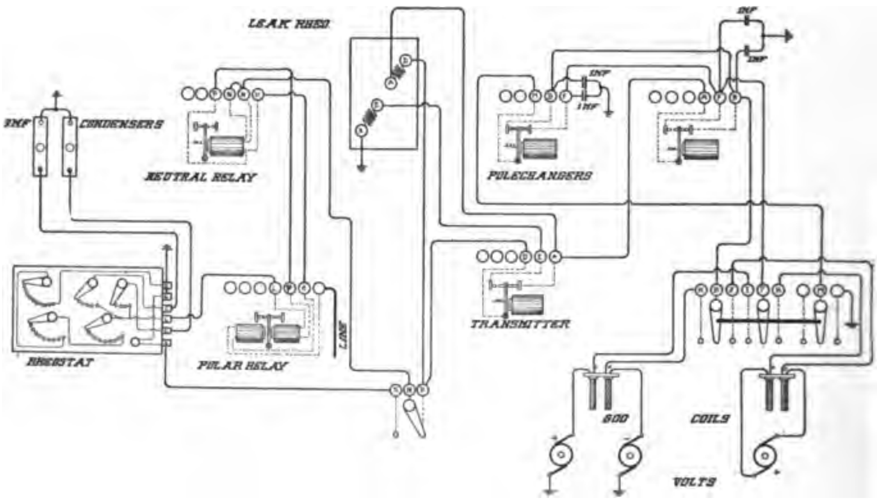


FIG. 265.—Instrument binding-post connections of combination single dynamo and double dynamo quadruplex.

This arrangement is efficient and economical, but its employment is advisable only where constant quadruplex service is not required.

Figure 263 shows the actual main-line binding-post connections of the single-dynamo quadruplex.

Figure 264 shows a diagram of the required switching connections of a quadruplex set wired to operate either as a single-dynamo, or as a regulation two-dynamo quadruplex, while Fig. 265 shows the actual instrument binding-post main-line connections of a set arranged to operate as a single- or a double-dynamo quadruplex.

METALLIC CIRCUIT QUADRUPLEX

Figure 266 shows the instrument and battery switchboard connections of a quadruplex set arranged for metallic circuit operation.

The system illustrated is arranged so that it may be used for grounded-circuit, or metallic-circuit operation. Throwing the switches to the left

provides for metallic-circuit operation, and throwing the switches to the right provides for single-line grounded circuit operation.

It happens sometimes that all of the wires along a particular route are so affected by induction from neighboring high-tension power circuits that quadruplex operation over single grounded circuits is impossible, or at best very unsatisfactory.

In such cases the metallic circuit quadruplex (using two main-line wires looped) has been found to give satisfactory results.

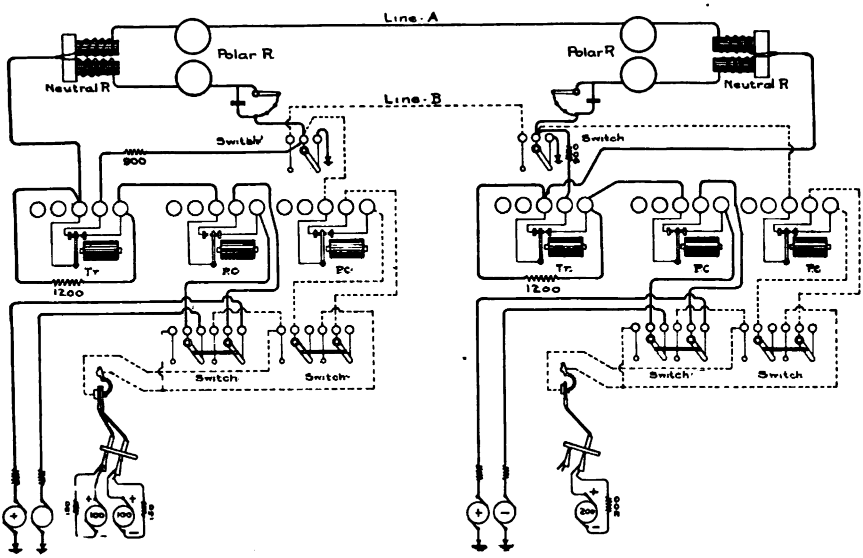


FIG. 266.—Field quadruplex arranged to be operated over a ground return circuit or a metallic circuit.

THE NEUTRAL-RELAY "KICK," AND THE "BUG-TRAP" METHOD OF COUNTERACTING ITS EFFECTS ON SOUNDER SIGNALS

As the student constructs diagrams showing the various positions of the armatures of the transmitters and pole-changers at each end of a quadruplex circuit as suggested in the schedule showing the sixteen possible combinations, it will very likely occur to him that the various battery and condenser actions incident to the operation of the four signaling keys, will result in constantly recurring intervals of no magnetism in the cores of the relays.

So far as the polar relay is concerned the period of no magnetism is of no consequence as its armature is held by a permanent magnet in the position into which it was last moved due to current in the relay coils, and will remain there until the current flowing through the relay coils has been reversed. Not so with the neutral relay, however, as the armature of the latter being acted upon by a retractile spring is drawn away from the electromagnet and

the closed contact point immediately upon the cessation of current in the coil windings, or upon reduction of the strength of current actuating the magnet.

It is understood that the direction of the current is reversed each time the armature of the pole-changer is caused to move from the positive to the

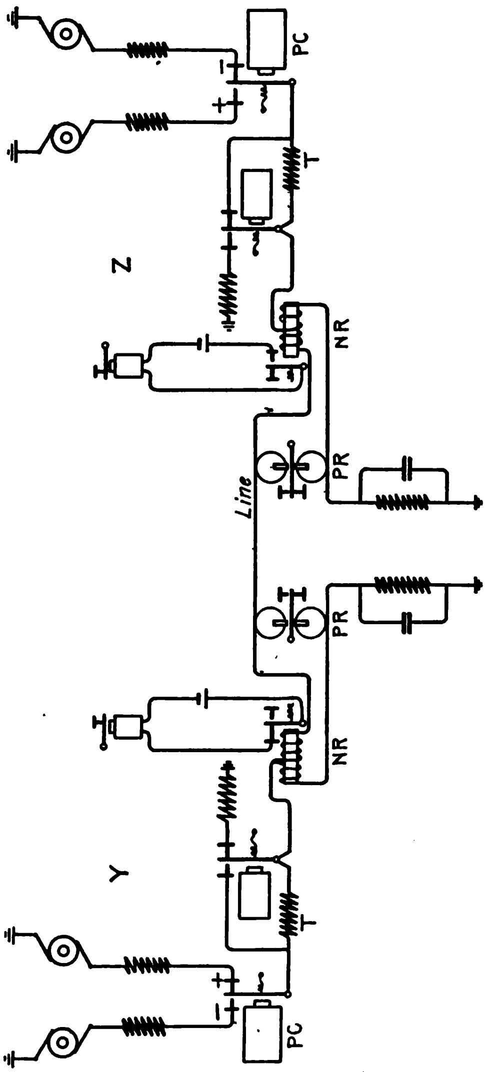


FIG. 267.—Quadruplex circuits showing the reading sounder circuit operated by the neutral relay.

negative battery contact, and *vice versa*. As the armature of the transmitter at *Z* (Fig. 267) is in the closed position, the armature of the neutral relay at *Y* will be in the closed position. If now the pole-changer at *Z* is operated, the first movement of its armature will be from the negative to the positive

battery terminal, which results in a reversal of the direction of current in the windings of the relays. This change, of course, requires time, as the current due to the negative battery must disappear and the current due to the positive battery must build up to the strength required to hold the armature of the neutral relay against its front-stop, and this entails an interval during which the magnets of the neutral relay are not magnetized. It is evident then, that at this instant the armature of the neutral relay—due to the action of the retractile spring—departs from its front-stop.

Fortunately this interval of no-magnetism is brief, and the armature has time to recede but a short distance before the magnetism has again built

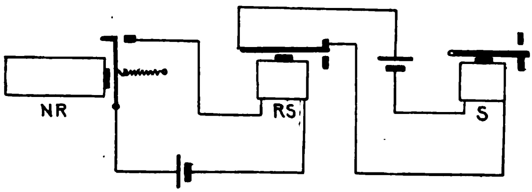


FIG. 268.—Repeating Sounder "bug-trap."

up to the strength necessary to attract it, due to current from the opposite battery pole, which in the interim has been applied to the line. But, although brief, the interval of no-magnetism frequently is of sufficient duration to cause a false signal to be produced on the reading sounder operated locally by the tongue of the neutral relay.

This disturbance is sometimes referred to as the "*B* side kick" and its objectionable effects are counteracted by devices variously arranged and known as "bug-traps."

The Repeating Sounder.—The earliest adopted method of bridging over the period of no-magnetism was that employing a "relaying" or "repeating" sounder, so called.

Figure 268 shows schematically the wiring of the receiving side "local" circuits of a quadruplex set equipped with a repeating sounder. It will be seen that the armature lever of the reading sounder *S*, is in the marking position while the armature tongue of the neutral relay is in contact with its front-stop, and it is evident that the armature of the reading sounder will not be released until the armature of the neutral relay has been drawn into contact with its back-stop. Obviously, a time element is introduced which consists of the time taken by the relay tongue to traverse the gap maintained between its front-stop and back-stop plus the time taken for the magnetism in the sounder magnets to build up to a strength sufficient to attract their armatures. The repeating sounder was purposely equipped with a heavy armature lever in order that it would possess considerable inertia and as a result thereof, be slow acting as compared with an instrument equipped with a light lever.

It was found in practice that during the period of reversal when all other conditions were favorable the tongue of the neutral relay had time to travel but a minute distance away from its front-stop before being called back by the resumption of magnetism in the cores of the magnet.

It might here be observed that when the short-end is to line at the distant station, there are no deleterious effects resulting from the reversals of polarity consequent to the operation of the distant pole-changer, as now the armature of the home neutral relay remains in contact with its back-stop and the armature of the reading sounder is in the non-marking position.

The Gerritt Smith Arrangement.—The Gerritt Smith neutral relay arrangement has in the past been used upon quadruplexes in both Western Union, and Postal Telegraph service, and at the present time is in use on a number of quadruplex sets on various railroad telegraph systems. A theoretical sketch of the arrangement is shown in Fig. 269. In the "Postal's" service the line coils were wound to a resistance of 150 ohms, and the "extra" coil to a resistance of 400 ohms, and as an additional protection the Diehl bug-trap (to be described presently) was also employed.

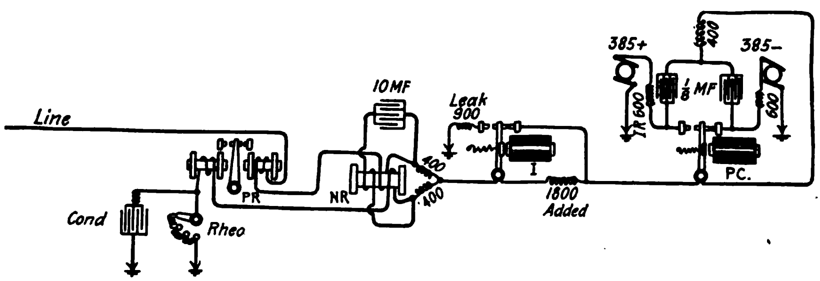


FIG. 269.—The Gerritt Smith neutral relay arrangement.

Figure 269 shows that in the "Smith" arrangement two 400-ohm coils form the "divide" for the main and artificial lines. The insertion of these coils is for the purpose of establishing a momentary difference of potential through the "extra" coil and condenser circuit which is "bridged" across the main-line and artificial-line circuits when battery is applied at the distant end of the line. When the resulting actions are traced it will be seen that while either pole of the distant battery is to line a difference of potential is established across the terminals of the condenser which results in the latter becoming "charged." At the instant of reversal of polarity at the distant station the condenser discharges through the extra coil, in a direction the reverse of that in which the operating current in the main- or artificial-line coils had been flowing. The result, therefore, is that the "turn-over" of magnetism in the cores of the relay magnets is hastened considerably, and the period of no-magnetism correspondingly shortened.

The insertion of the 400-ohm coils at both ends of the line naturally increases the total resistance of the circuit 800 ohms, which is an undesirable thing to do, as the increased resistance reduces the efficiency possible where these 400-ohm resistances are not inserted in the line. One method of eliminating the objectionable additional resistance, which permits of retaining the efficacious features of the Smith arrangement is that of transposing the positions of the polar and the neutral relays, for the purpose of utilizing the resistance of the coil windings of the former in place of the 400-ohm resistance coils usually connected at the divide.

Figure 270 shows a view of the Smith Neutral Relay, in which it may be seen that this instrument is identical in construction and design, with the

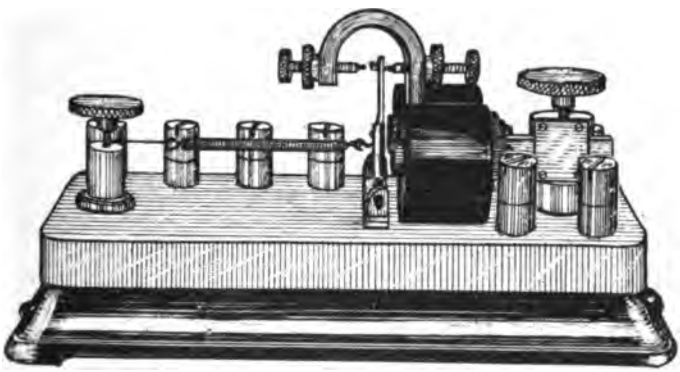


FIG. 270.—Neutral relay with extra binding posts to which are attached the terminals of the extra windings.

ordinary form of neutral relay, with the exception that two additional binding-posts are provided for the terminals of the extra coil, which consists simply of a third winding over the cores of the magnets carrying the main-line and artificial-line windings.

The Diehl "Bug-trap."—Another very effectual method of tiding over the period of reversal is that whereby a "bug-trap" relay (*BT*, Fig. 271) in connection with the back-stop of the neutral relay, is used to introduce a time element during which the armatures of the neutral relay and the bug-trap relay must traverse the gap separating their back- and front-stops before a signal will be registered on the reading sounder.

A glance at the diagram will show that while the armature of the neutral relay may flutter uncertainly against its front-stop during reversal of the long-end battery at the distant end of the line, the armature of the reading sounder will remain undisturbed and in the marking position until the armature tongue of the relay has fallen into contact with its back-stop.

The Diehl bug-trap is extensively employed in the quadruplex service of the Postal Telegraph-Cable Company.

The Differential "Bug-trap."—Figure 272 shows a "bug-trap" arrangement employing a differentially wound bug-trap relay which in a somewhat different manner accomplishes the same purpose as the Diehl bug-trap relay, and the repeating-sounder arrangement previously described.

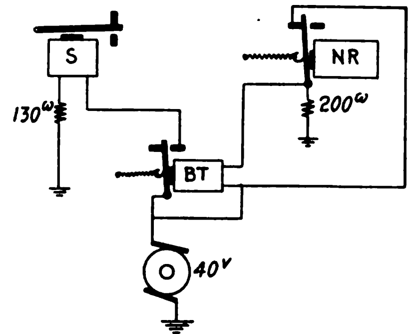


FIG. 271.—The Diehl bug-trap.

Bug-trap Suitable for Use on Neutral Side of "Decrement" Quad.—While general practice provides for the operation of the neutral side relays by an "increment" of current, there may be special cases where it is advisable to keep the long-end battery to line normally, and to operate the distant neutral relay by a "decrement" of current.

To make this possible the only circuit change necessary at the sending end is to transpose the neutral side transmitter connections so that the closed key will cause the lower potential to be placed to line and the open key the higher potential.

When a quadruplex is so arranged that the operation of the neutral relays is the result of a decrement of current strength, it follows that the reading sounder must "close" when the armature tongue of the line relay makes contact with its back-stop instead of with its front-stop as with the more common arrangement.

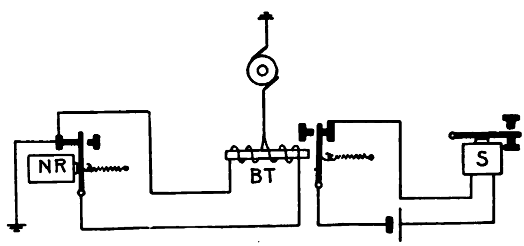


FIG. 272.—Differential bug-trap relay.

Figure 273 depicts a differential bug-trap arrangement which provides that the armature of the reading sounder will be in the marking position while the armature tongue of the neutral relay is in contact with its back-stop, and in the non-marking, or "spacing" position while the relay armature is not in contact with its front-stop.

The "Condenser" Bug-trap.—A neutral-side reading sounder arrangement used in British Post Office telegraph practice which has been found to give excellent results, is illustrated schematically in Fig. 274. The reading sounder *S*, has a resistance of 1,000 ohms, but as there is a 9,000-ohm shunt around the coils of the sounder the actual or joint-resistance of that portion of the circuit is 900 ohms.

The 50-ohm coil is placed in the circuit for the purpose of curbing the

sparking that would appear at the contact points of the relay due to the discharge from the condenser when the circuit is completed. The capacity of the condenser may be varied from 2 to 8 m.f. according to the requirements of the line wire operated, while the resistance in series with the sounder may be varied from 100 to 700 ohms in steps of 100 ohms. The purpose of the variable resistance is to "time" the discharge from the condenser and the discharge due to inductance in the coils of the sounder, thus making it possible to prolong the magnetization of the cores of the sounder magnets over the period required to maintain the armature of the reading sounder in the marking position while the armature of the relay momentarily breaks circuit during the periods of reversal at the distant station.

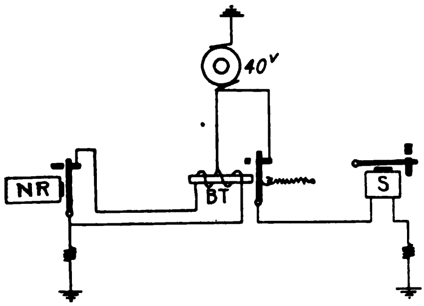


FIG. 273.—Differential bug-trap arrangement for use on neutral side of "decrement" quadruplex.

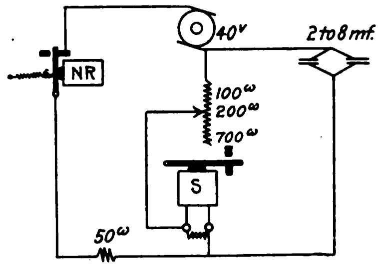


FIG. 274.—Condenser bug-trap.

If the circuits shown in the diagram are carefully traced it will be seen that while the armature of the relay is in the closed position the condenser takes a charge due to the difference of potential which exists across the terminals of the sounder. Now, if while the relay tongue is in contact with its front-stop the polarity to line at the distant station is reversed, there will be a momentary break in the sounder circuit controlled by the armature of the neutral relay. At the instant, however, that this occurs the condenser discharges through the only circuit presented to it—through the sounder. The discharge from the condenser and the discharge due to the inductance of the sounder magnets results in prolonging the magnetization of the cores of the sounder until current from the opposite battery pole at the distant end of the line has had time once more to resume control of the armature of the neutral relay.

THE FREIR SELF-POLARIZING NEUTRAL RELAY

Of the various attempts that have been made from time to time, to develop a type of relay for the "second" side of the quadruplex, which would meet the requirements more satisfactorily than the ordinary types of neutral

relay; the product which has survived longest is that known as the Frier relay, the theoretical arrangement of which is illustrated in Fig. 275.

The moving element—the armature—of this relay is pivoted in a socket formed in the pole-piece of an extra electromagnet which is wound differentially and connected into the main line, and artificial line circuits in the same manner as the regular line coils C and C_1.

A current in the extra coil C_2 will result in the core of that magnet having north polarity at one end and south polarity at the other end. Now if the end of the core upon which the armature (Fig. 275) stands, is at a particular instant a north pole, the armature extending upward between the pole-faces of the two regular magnets will be magnetized inductively and have a north polarity, and, as obviously the windings of the two regular coils are so connected that when current flows in the circuit made up through them, the pole-pieces facing the armature will at all times have opposite polarities; it is evident that the polarized armature will move toward the pole-piece which at that instant is a south pole.

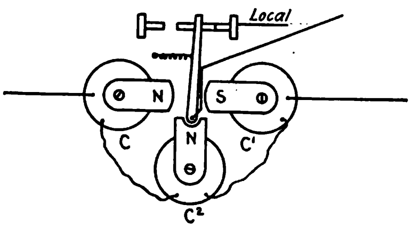


FIG. 275.—Theory of the Frier neutral relay.

The office of the extra coil is to maintain the polarity of the armature at all times in opposition to the coil C_1 regardless of the direction of the current flowing in the circuit.

In Fig. 275 the magnet on the left is shown as presenting a north pole, while the magnet on the right presents a south pole to the armature, and as the latter possesses north polarity the result is that it has been repelled from the left-hand magnet and attracted by the right-hand magnet. Should the line current at the distant station be reversed while the armature of the relay is in the position shown, the right-hand magnet will present a north pole to the armature; but as at the instant the magnetism in the right-hand magnet is reversed, the magnetism of the core of the extra coil also is reversed (and consequently, also the polarity of the armature) the armature remains in connection with the closed-contact as long as the long-end battery at the distant station is to line.

The method by which the armature of the relay is made immune to short-end reversals from the distant station, is the same as that employed in the operation of the ordinary neutral relay; namely by attaching a retractile spring to the armature, and giving it a tension sufficient to hold it away from the closed-contact when the short-end only is to line.

Adjustment of the Freir Relay.—Under ordinary line conditions, the best adjustment to give the armature of the Freir relay is such that the gap between the armature and the left-hand magnet will be about twice as

wide as that separating the armature from the pole-face of the right-hand magnet.

OTHER METHODS OF TIDING OVER THE PERIODS OF REVERSAL

From what has hereinbefore been stated in regard to the necessity of establishing a time interval during which the armature of the second-side relay may be made to ignore, as it were, the period of "no-current" which exists while the long-end current at the distant end of the line is reversed, it would seem of the utmost importance that the "reversal" should be made with the greatest possible speed, and that anything which can be done to hasten the movement of the armature of the pole-changer between back- and front-stops during operation, will have a directly beneficial effect upon the operation of the distant neutral relay, since reducing the period of no-current correspondingly minimizes the task set for the bug-trap arrangement employed in any given system.

It might here be restated, as covered more fully elsewhere herein, that close adjustment of the points of the pole-changer between which the armature tongue plays, will accomplish more in the way of reducing the interval of no-current, than anything else that may be contributed. The best practice in this regard is that wherein the adjustment of pole-changer and transmitter points brings the opposite contact-points as close together as sparking will permit.

THE SHORT-CORE OF THE NEUTRAL RELAY

In the design of nearly all forms of neutral relays, advantage has been taken of the fact that by reducing the length of the iron core the magnetism builds up to its full strength more rapidly than where comparatively long cores are employed in winding electromagnets.

NEUTRAL RELAYS WITH HOLDING COILS

When the Jones quad was the standard of the Postal Telegraph-Cable Company, prior to the adoption of the Field key system, the neutral relay was equipped with a third coil which at the instant of "reversal" was charged by means of a form of induction coil known as the inductorium.

THE INDUCTORIUM

The inductorium consisted of an iron core upon which three coils were wound, one coil connected in series with the main line coils of the two line relays, another in series with the artificial line coils of the relays, while the third

coil had its terminals connected directly to the winding of the third coil of the neutral relay; the latter when energized serving to hold the armature of the relay in the closed position for a brief instant, or during the reversal of the distant line-battery.

Reversal of the battery at the distant station resulted in an induced current being set up in the third coil (the secondary winding) of the inductorium, which in turn energized the "holding-coil" of the neutral relay at the critical moment, thereby tending to hold the armature of the relay in contact with its front-stop during the moment of no-magnetism in the line coils of the relay.

HOLDING COIL OF THE NEUTRAL RELAY EMPLOYED IN THE PRESENT WESTERN UNION QUADRUPLEX

The quadruplex which at the present time is the standard in the service of the Western Union Telegraph Company, includes a form of neutral relay which is equipped with a holding coil, somewhat similar in action to the inductorium. The coil is placed in series with a condenser and is connected across the main and artificial lines, being energized at the instant the distant pole-changer "breaks" contact with either battery pole.

The effect of this holding coil upon the efficiency of the second side of the Western Union quadruplex, will be described more in detail, when, presently, the principles of that quadruplex are explained.

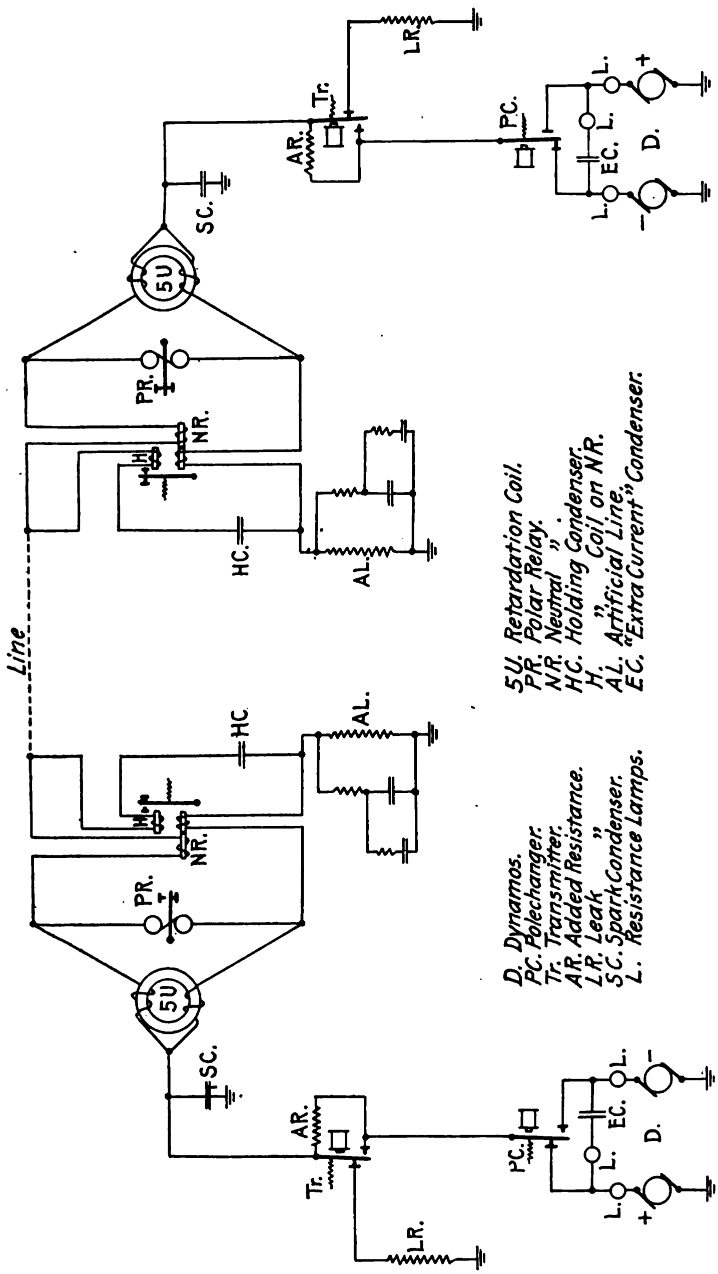
THE WESTERN UNION QUADRUPLEX

Figure 276 shows a theoretical diagram of the quadruplex recently adopted as standard by the Western Union Telegraph Company.

The improvements incorporated in this system include a form of pole-changer invented by Mr. S. D. Field and illustrated in skeleton in Fig. 277.

Like the pole-changer used in connection with the Postal Telegraph-Cable Co.'s quadruplex, this instrument may be used also as a "transmitter" on the second side of the quad. The magnet on the left of the armature has a solid iron core, while the magnet on the right has a laminated iron core and is somewhat shorter than the former. Each magnet is wound to a resistance of 4 ohms, making a total of 8 ohms for both magnets in series, and the respective coils are so wound that the magnetism developed in each pair of coils when the transmitting key is depressed, is of such polarity that the action of one magnet opposes that of the other. The armature is situated between the opposing pole-faces of the electromagnets and has attached to it a retractile spring which holds the armature normally toward the left-hand magnet.

When the transmitting key which controls the operation of the pole-changer is depressed, both magnets are energized, but the magnetism builds up



D. Dynamos.
PC. Polechanger.
Tr. Transmitter.
AR. Added Resistance.
LR. Leak "
SC. Spark Condenser.
L. Resistance Lamps.

5U. Retardation Coil.
PR. Polar Relay.
NR. Neutral " .
HC. Holding Condenser.
H. " Coil on NR.
AL. Artificial Line.
EC. "Extra Current" Condenser.

FIG. 276.—Western Union standard quadruplex. Theory.

much more rapidly in the right-hand magnet than in the other, due to the fact that the former is considerably shorter and that it has a laminated iron core, and to the further fact that in practice the coils of the longer magnet are shunted with a resistance coil, the total result of which is that the left-hand magnet does not acquire its maximum magnetic strength until the armature has been drawn into contact with the main-line battery contact on the right; remaining there until the signaling key is released or opened.

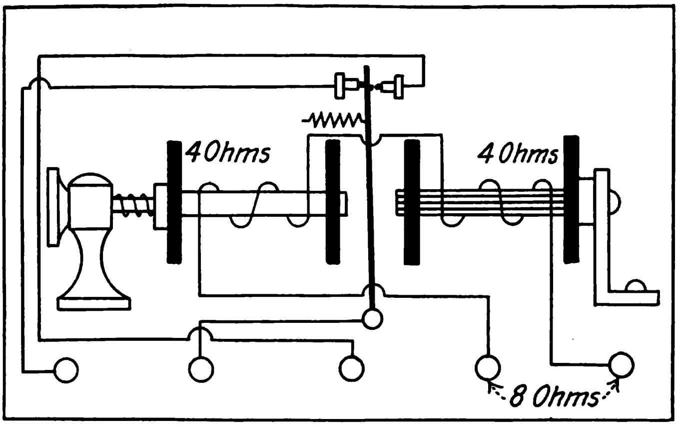


FIG. 277.—Form of pole-changer and transmitter used in connection with the W. U. quadruplex.

At the instant the signaling key is released—thus opening the battery circuit through the coils of the pole-changer—the laminated core of the right-hand magnet instantaneously loses its magnetism, permitting the retractile spring aided by the slowly disappearing magnetism in the long core, to rapidly draw the armature into contact with the opposite battery contact.

The object aimed at is to hasten the transit of the armature, thereby reducing to a corresponding degree the interval during which the main-line battery is not applied to the line.

THE W. U., NEUTRAL RELAY

Figure 278 shows in skeleton the usual differential windings of the main-line and artificial-line circuits, each wound to a resistance of 350 ohms, while situated immediately above the line magnet is shown a "holding" magnet.

It is evident from the circuit arrangements illustrated in Fig. 276 that this quadruplex embodies principles common to the "bridge" and to the "differential" multiplex systems, inasmuch as the polar relay occupies a position the same as that occupied by the relay used in the bridge duplex, while the neutral relay has one of its windings connected in series with the main-line wire, and the other in series with the artificial-line circuit.

The Holding Coil.—As shown at *H*, Fig. 276, the holding coil is connected across the main and artificial lines in series with a condenser *HC* which accumulates a charge while battery is applied to the line at the distant station. As the distant pole-changer armature leaves either battery contact, the home condenser almost immediately thereafter discharges through the path provided for it—through the holding coil—thus tending to hold the armature of the neutral relay in the closed position during a period which approximates in duration that required by the armature of the distant pole-changer to travel from one battery contact to the other.

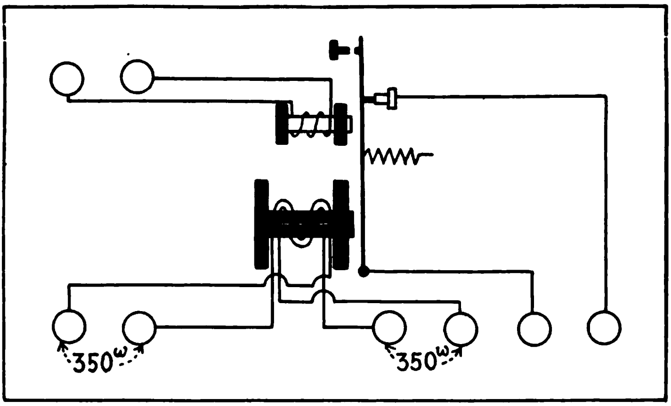


FIG. 278.—Neutral relay used in connection with the W. U. quadruplex.

The Impedance Coil.—In the bridge duplex, Fig. 233, page 268, the four arms of the bridge consist of the line wire, the artificial line, the arm *r′*, and the arm *r*. The latter two resistances have identical values. In British Post-office telegraph practice each arm is given a value of 3,000 ohms.

In the quadruplex under consideration the corresponding arms are represented by the two windings of an impedance or retardation coil (5*U*, Fig. 276) which has a circular core built up of iron wires forming a closed magnetic circuit. The windings are differential, each coil having a resistance of 500 ohms.

In the bridge duplex, employing non-inductive resistance units to form the two "bridge" arms, the operation of the polar relay is dependent upon the existing difference of potential across the terminals of the relay, which necessitates that in order to have an operating current of sufficient value to insure quick responce of the relay armature, the resistance of the "arms" of the bridge must be high enough to maintain the required difference of potential.

When the non-inductive bridge arms are replaced by arms possessing a considerable amount of retardation or impedance, the operation of the polar

relay is not dependent solely upon the difference of potential existing across its terminals, as, in this case (see Fig. 276) the received current finds a less obstructed path through the relay than through the upper arm of the bridge coil, because the latter presents "impedance" which "retards" the flow of current into it: at least, the first part of each received current wave is diverted through the relay, causing it to actuate its armature without having to wait for the current due to difference of potential across the bridge arms.

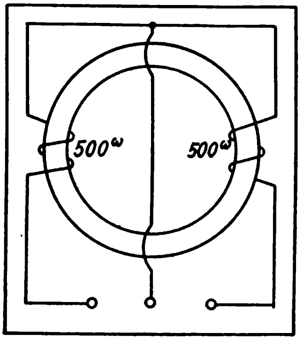


FIG. 279.—5-U impedance coil.

The Ohm's law current, of course, builds up gradually as the magnetic inertia of the retardation coil is overcome, and, if the circuit is properly timed, in this regard; comes along in time to hold the armature of the relay in the desired position.

In view of the fact that the first part of the received impulse is diverted through the relay circuit it is not necessary (on account of the inductance possessed by the alternative path) to have high ohmic resistance in the bridge arms.

In the Western Union arrangement, therefore, each coil has a resistance of 500 ohms instead of the 3,000 ohms per arm used in the old form of bridge duplex. Indeed, it has been found practicable in ocean cable duplex operation to employ bridge arms having a resistance of 15 ohms each, but in this case the coils are of large dimensions and have an inductance of 15 henries each.[1]

EFFECT OF THE 5-U COIL UPON OUT-GOING CURRENTS

The fact that the windings of the coil are differential, and that the action of one coil neutralizes the action of the other; so far as the magnetic effects produced in the iron are concerned, provides that to out-going currents there will be no appreciable retardation.

It is obvious that with equal current strengths in each coil of the bridge, no magnetism is produced in the core. This being the case the situation is the same as if no iron core were inserted within the coils; or, as if the coils were simple solenoids.

We are dealing with the characteristics of the magnetic field set up in the space immediately surrounding the coil windings, and inasmuch as there is no magnetism in the core, the "extra current" due to self-induction will be of low value in comparison with that which would be produced due to the stronger magnetic field were the core magnetized. Consequently, as the

[1] The "bridge-resistance" used in ocean cable work is known as the Brown magnetic bridge, being the invention of Mr. S. G. Brown.

impedance presented to the out-going impulses, would consist mainly of the reverse, or opposing currents due to self-induction of the coil, it is at once apparent that the impedance will be less when the core is not magnetized.

Naturally there will be a certain amount of "choke" due to the contiguous turns of the winding of the coil in either arm, but this is small in comparison with what it would be in one coil, were the circuit through the companion coil opened; or, if the windings were not differential.

The amount of retardation natural to the coil winding graduates the rise and fall of the out-going currents, and this in connection with the spark condenser (*SC*, Fig. 276) reduces considerably the strength of the electrostatic induction which otherwise would take place between the line wire and neighboring conductors on the same pole line, or in the same cable.

THE EFFECT OF THE 5-U COIL UPON THE HOME RELAYS

It is needful now to look to the effects produced in the home receiving relays due to the action of the bridge coil.

Obviously, the only time when there is no magnetism in the core of the bridge coil is when identical current values obtain in both main and artificial lines. The operation of the distant pole-changer, naturally, causes magnetic variations in the core of the retardation coil at the home station, and the extra currents produced as a result thereof traverse the coils of the polar relay in a direction which aids the incoming currents from the distant station in effecting the movement of the armature of the relay in the desired direction. Also, under certain conditions during the period of reversal at the distant station, the instant the armature of the pole-changer leaves either battery contact, magnetic variations in the home bridge coil produce extra currents, which, having a path across the main line and artificial line by way of the holding coil of the neutral relay, aid the discharge current from the condenser *HC* in holding the tongue of the neutral relay in contact with its front-stop during the critical period.

OPERATION OF THE W. U. QUAD

By referring to Fig. 276, it will be seen that the line currents are furnished by two dynamos, the negative pole of one machine being connected to the "closed" contact of the pole-changer, while the positive pole of the other dynamo is connected to the "open" contact of the pole-changer; the opposite pole of each dynamo being grounded.

The ratio of long-end to short-end current is 3 to 1, and the method employed to obtain the desired proportions is the same as in the Field quadruplex. In Fig. 276, the added resistance is shown at *AR* and the leak resistance at *LR*.

At the station shown on the left the pole-changer *PC* is represented as sending a positive current to line, the strength of which has been reduced to the short-end value on account of having a joint-path; on the one hand via the added resistance *AR*, to ground at the distant station, and at the end of the artificial line at the home station: on the other hand from the pole-changer armature to ground at the home station via the leak resistance *LR*. None of the out-going current will pass through the coils of the polar relay provided the resistance of the artificial line has been adjusted to equal that of the main-line and distant apparatus to ground, for the reason that under such conditions there is no difference of potential across the terminals of the relay. The same is true of the holding coil *H*, of the neutral relay.

In the case of the neutral relay and the retardation coil, it is seen that each of these instruments has wound upon its iron core one coil in series with the main-line wire, and one coil in series with the artificial line circuit. In other words each instrument is wound differentially, with the result that when equal current strengths obtain in each winding, the tendency of one coil to magnetize the core is nullified by the action of the companion coil.

It is plain, therefore, that under well-balanced conditions the home relays are unresponsive to out-going signals.

The action of the received current may be traced by assuming that a short-end impulse has been transmitted from the station on the left to the station shown on the right (Fig. 276). Obviously, the current passes through the main-line coil of the neutral relay *NR*, and through the holding-coil *H* (in the winding of the latter the current exists only while the condenser *HC* is taking on its charge), but as the retractile spring attached to the armature of the neutral relay has previously been given a tension which holds it in contact with its back-stop until the long-end potential has been applied at the distant end of the line, the relay is unaffected. After passing through the line coil of the neutral relay the received impulse finds two paths open to it; one through the polar relay *PR*, and one through the coil 5*U*. In attempting to enter the line coil of the latter, the current upsets the magnetic balance of the coil by magnetizing the core (due to the increased current volume now flowing in one winding over that flowing in the other) with the result that the extra current of self-induction thereby created, opposes the flow of the line current; momentarily at least, or until the head end of the received current wave has been diverted through the path containing the polar relay.

As the armature of the polar relay is moved into the closed or marking position, the current builds up through the line winding of the impedance coil, and joins that portion of the current which has passed through the polar relay and the other winding of the impedance coil, passing thence to ground via the transmitting instruments and dynamo.

Figure 280 shows the actual instrument binding-post connections of

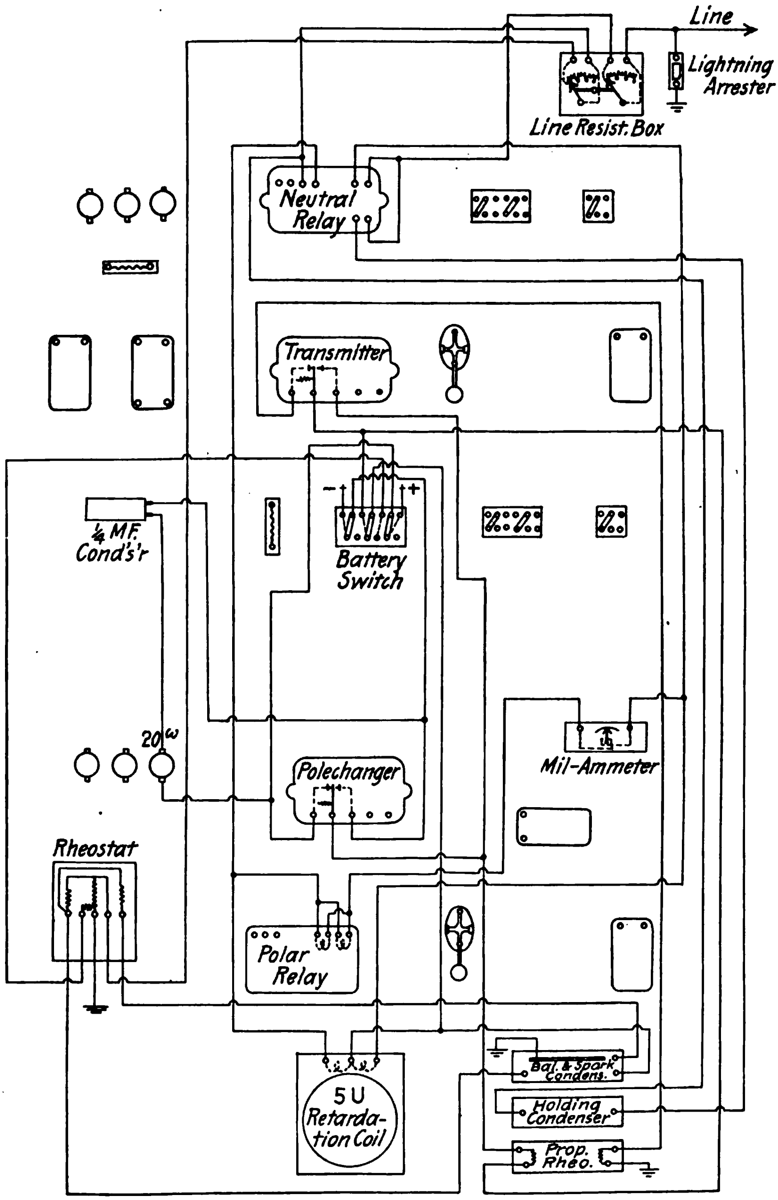


FIG. 280.—Instrument main line binding-post connections W. U. quadruplex.

the Western Union quadruplex. The "Line resistance box" shown in the upper right hand corner of the diagram (an enlarged view of which is shown in Fig. 281) is made up of two independent variable resistances, of 1,250 ohms total each, equipped with a common double-lever switch for the purpose of throwing equal amounts of resistance into the main line and into the artificial line simultaneously.

One use to which this resistance is put, is to increase the resistance of comparatively short lines which it is desired to operate quadruplex with the regular long-line potentials. Inserting additional resistance in both main and artificial lines adds to the electrical length of line wires which in

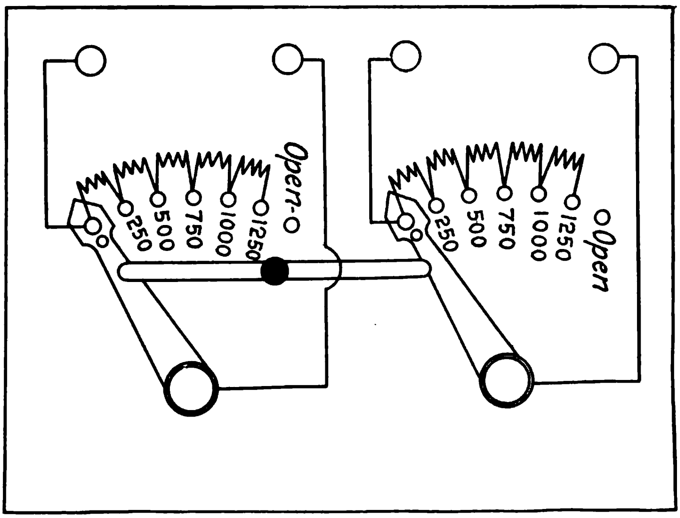


FIG. 281.—"Line" resistance box W. U. quadruplex.

themselves would be so low in resistance that the currents from the regular dynamos would be excessive.

The insertion of added resistance in the line immediately in front of the home apparatus is of considerable benefit in caring for quick changes in the insulation of the line wire during wet weather, for the reason that with 800 or 1,000 ohms of the external circuit perfectly insulated from the ground (as would be the case when that much added resistance is inserted in series with the line) the insulation of the entire line, per electrical mile, is considerably higher, and as a consequence permits of greater variation in the resistance of the exposed section of the line, without seriously affecting the "balance." It is necessary, of course, when such additional resistance has been inserted in the line at one end of a quadruplexed circuit, to notify the distant office of the fact, so that the line balance at the distant end may be changed to compensate for the added resistance.

THE MILAMMETER

The milammeter shown in the diagram, Fig. 280 (an enlarged view of which is shown in Fig. 282) is connected in series with the polar relay in the bridge circuit for the purpose of facilitating the operation of balancing.

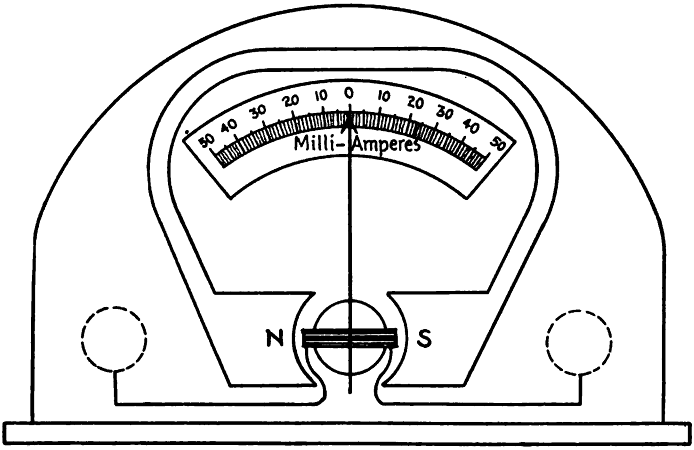


FIG. 282.—Milammeter used in "balancing" duplexes and quadruplexes.

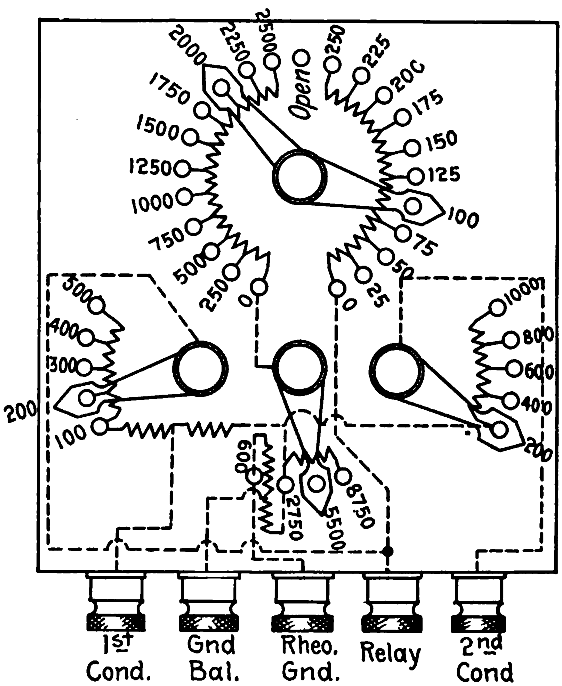


FIG. 283.—W. U. artificial-line rheostat.

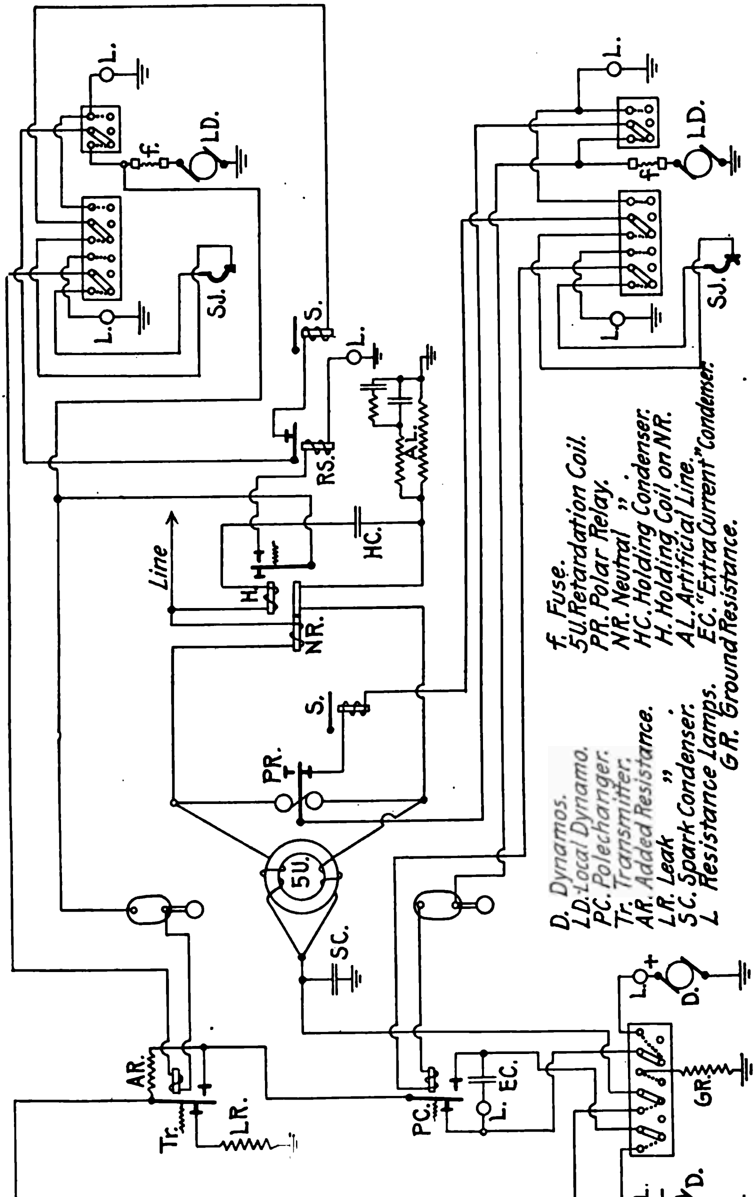


FIG. 284.—Local and main line connections W. U. quadruplex.

Figure 283 shows the binding-post connections of the artificial-line rheostat.

Figure 284 is a diagram of the connections of both main-line and local circuits of the W.U. quadruplex. The spring-jacks *SJ* represent the loop-board terminals of the receiving and sending "sides" of the polar and common sides of the set.

THE BRITISH POST-OFFICE QUADRUPLEX

The quadruplex system used in British Post-Office telegraph service, is, in theory, practically the same as the original American quadruplex systems.

A theoretical diagram of the main-line circuits is shown in Fig. 285, a consideration of which will show that the "increment key" *IK* serves the same purpose as the transmitter employed on the second side of the American systems; namely to place either the short- or the long-end battery to line, while the "reversing key" *RK* serves as a pole-changer.

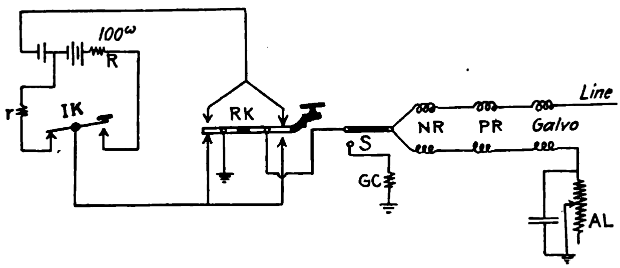


FIG. 285.

In the diagram submitted herewith the transmitting keys are shown in American conventional outline, for the purpose of clearly portraying the action of each instrument. The actual appearance of one key is about the same as that of the other. Both are larger and more massive than the American key, and the contact points—which are mounted at the end of the key remote from the hard-rubber knob—are enclosed in a dust-proof metal cylinder with a glass top, see Fig. 285*a*.

The reversing key, or *A* key as it is termed in Great Britain has its battery contact point so arranged that the continuity of the circuit from the battery is preserved while the lever passes from positive to negative battery terminal or *vice versa*. Obviously a momentary short circuit exists during the reversal of current, the same as in the case of the continuity preserving transmitter employed in connection with the Stearns duplex.

The increment, or *B* key is so constructed that the battery is never cut off from the *A* key. In order that this may be satisfactorily accomplished

it is necessary to so adjust the contact points that the lever will make contact with one battery terminal before breaking with the other.

For the purpose of curbing the sparking at contact points when full potential is to line a 100-ohm resistance coil is connected as shown at *R*, Fig. 285.

It is necessary that the resistance of the battery should be the same regardless of the position of the keys at any instant, otherwise the balance

FIG. 285*a*.—Transmitting key, B. P. O. quadruplex.

at the distant station would be disturbed when the positions of the keys are altered. It is necessary, therefore, to insert a resistance *r* in the tap wire equal to the resistance of the long-end battery, plus the 100-ohm spark coil. With the key *IK* in the position shown in the diagram the internal resistance; including that of the short-end battery, is the same as that obtaining when the key is depressed.

The type of polar relay used is that known as the Wheatstone relay.

The differential neutral relay, or *B* relay, has its local connections arranged as shown in Fig. 274.

CHAPTER XV

"BALANCING" DUPLEXES AND QUADRUPLEXES

If the reader will review that part of Chapter XIII, dealing with "The Differential Relay" (Fig. 217), and "The Artificial Line" (Fig. 218) he will recognize the necessity for a correct "ohmic" and "static" balance of lines operated duplex or quadruplex.

In describing the various duplex and quadruplex systems in the preceding text matter, "methods" of balancing each system have been purposely omitted, for the reason that with all systems the requirements are the same, and that the author during a fairly extensive teaching experience has found that no little confusion exists in the minds of students, when the idea prevails that each system—so-called—of duplex or quadruplex telegraphy can be balanced only by some particular process or method.

It is true that the various telegraph administrations furnish "rules" for the guidance of employees in balancing the particular duplex and quadruplex employed in each case, some of which will be incorporated herein; but it should be borne in mind that the procedure in every instance has the same purpose in view, viz., that of establishing an "ohmic" and "static" balance between the main-line wire and the artificial line.

THE RESISTANCE, OR "OHMIC" BALANCE

In Fig. 286, the artificial line rheostat is shown as having a resistance of 2,400 ohms. Although of secondary importance—so far as the balance is

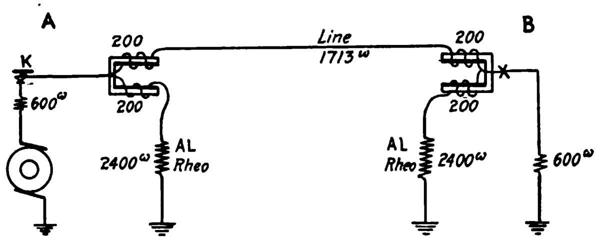


FIG. 286.—Balancing the main and artificial lines.

concerned—it is well to learn what the unplugged resistance of the rheostat represents.

In the typical case presented in Fig. 286, as in all similar installations, the 2,400 ohms in the rheostat at station *A* represents the resistance of the

line wire beyond the home relay, the resistance of the main-line coil of the relay at B, plus the joint-resistance of the artificial-line circuit to ground (including the resistance of the artificial-line coil of the relay) and the circuit to ground via the battery or dynamo; or,

$$\frac{600 \times (200+2400)}{600+(200+2400)}=487 \text{ ohms}$$

and

$$487+200+1,713=2,400 \text{ ohms.}$$

The indicated resistance of the artificial-line rheostat at A, therefore, represents the 1,713 ohms line resistance, plus the resistance of the main-line coil of the relay at B (in this case 200 ohms) plus the joint-resistance of the battery circuit and the artificial-line circuit from the point X at B.

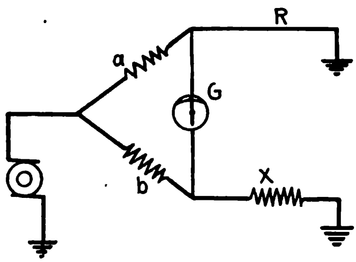


FIG. 287.—Principle of the bridge balance.

The reason why the resistance of the relay at A does not enter into the calculation is that the resistance of one side already balances the resistance of the other. If, for instance, the resistance of the artificial-line coil were regarded as a part of the total resistance of the artificial line, then the resistance of the main-line coil of the relay would have to be regarded as a part of the total line resistance, and the indicated resistance of the rheostat would remain the same.

That this is true may readily be seen by considering the conditions of current obtaining in a wheatstone bridge circuit, see Fig. 287.

The "bridge" coils a and b occupy the same positions in the circuit that the AL and ML coils of the differential relay occupy in a duplex or quadruplex circuit, while the bridge arm R represents the line wire, and the arm X the artificial line of a duplex or quadruplex circuit. The galvanometer G is connected across the terminals of the coils a and b for the purpose of indicating the presence of current in the galvanometer circuit.

As was explained in describing the principle of the Wheatstone Bridge (Fig. 138) no current will flow through the galvanometer circuit when the resistance of a equals the resistance of b and the resistance of R equals the resistance of X. Therefore, if in the duplex or quadruplex circuit the resistance of one winding of the relay equals the resistance of the other winding, the circuit will be balanced when the resistance of the rheostat is adjusted to equal the resistance of the line wire to ground via the distant apparatus.

It is apparent also, that the resistance of the rheostat will remain the same regardless of the resistance of the coils of the home relay, provided the

resistance of each coil is the same. In Fig. 286, for instance, the rheostat resistance (2,400 ohms) would remain the same and the home balance would be unaffected if the resistance of the home relay were changed to, say, 20 ohms instead of 200 ohms per winding.

The resistance balance may be established by adjusting the resistance of the artificial-line rheostat until the armature of the differentially connected polar relay, neutral relay, or galvanometer remains passive to the operation of the home pole-changer while the line is grounded at the distant station, and in the case of a "bridged" polar relay or galvanometer; until the armature and pointer, respectively, of those instruments indicate "no current."

THE CAPACITY, OR "STATIC" BALANCE

As pointed out elsewhere herein, when battery is applied to a line the conductor has to be "charged" before the recording instrument at the distant end of the line will indicate the presence of current in its coil windings.

When the key *K* is closed (Fig. 286) a rush of current takes place into the circuit which possesses capacity—the line wire—passing through the main-line coil of the relay, magnetizing its core momentarily, thereby producing a kick of the armature which seriously interferes with intended signals. Also, upon opening the key the line "discharges," again, momentarily energizing the main-line winding of the relay, thereby producing a false signal.

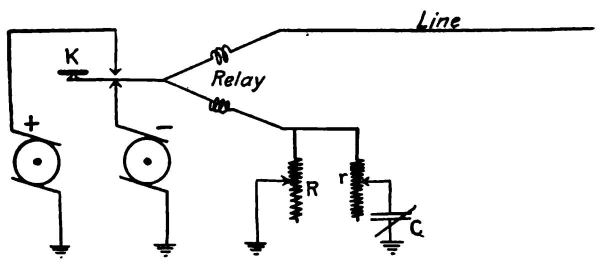


FIG. 288.

The above described action takes place when the circuit has been given an "ohmic" balance, only. When, however, the artificial line has been provided with artificial capacity in the form of an adjustable electric condenser connected across the terminals of the rheostat as shown in Fig. 288, a "capacity" balance may be established, so that the charges and discharges in the artificial-line circuit will at all times equal those in the main line.

When battery is applied to a line wire the distant end of which is "open," or insulated from the earth, the value of the charge may be represented as in Fig. 289. In the illustration the negative pole of the dynamo is "earthed"

or grounded, while the positive pole is applied to the line, giving the line a positive charge.

If after the wire has been charged, the lever of the switch S is moved into contact with the ground connection G, the charge will flow out of the line to ground.

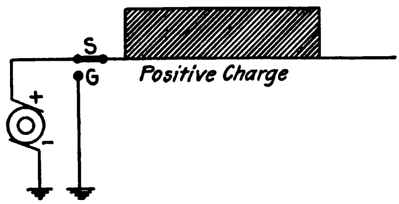


FIG. 289.

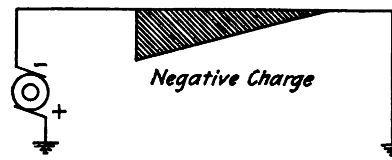


FIG. 290.

The assumed rectangular shape of the charge in this case is due to the fact that the same difference of potential exists throughout the entire length of the line.

The charge held by a line wire which is grounded at the distant end may be represented as in Fig. 290, and as in this case the negative pole of the dynamo is applied to the line, giving the latter a negative charge; the shaded area is shown below the line.

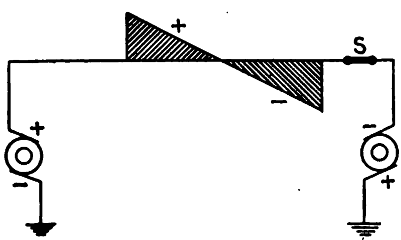


FIG. 291.

It will be seen that the value of the charge along the conductor "drops" with the potential. In other words, the value of the charge is greatest at the battery end of the line; the value decreasing directly with decrease of the difference of potential along the conductor; between the line and the earth, until finally when the zero potential of the earth obtains, the charge has zero value. It may be noted that the amount of charge held by the conductor—as represented by the area of the shaded section—in the case of the open wire, is twice as great as that held by the grounded wire, assuming, of course, that the value of the applied e.m.f. is identical in each instance.

When battery is applied at both ends of a line, positive at one end and negative at the other, the two charges held will be distributed as illustrated in Fig. 291. In this case there is a fall of potential from each end of the circuit toward the center, and, as at the electrical center of the line the potential will have zero value, the charge at that point will be nil.[1]

[1] In practice the electrical center may be far from the geographical center of the line. A circuit, for instance, may include a comparatively small coil of wire which has a resistance equal to many miles of line wire, and as the potential falls directly as resistance is overcome,

It will be seen that if the switch S (Fig. 291) were opened, the charge upon the line would take the form illustrated in Fig. 289, and it is evident that in the operation of duplex and quadruplex circuits all of these conditions of charge will obtain at different times during actual operation, and that the office of the condenser associated with the artificial-line at each end of the main-line is to produce in the artificial circuit, effects identical with those occurring in the main line at any given instant.

As before stated the terminals of the rheostat are shunted by a condenser (or pair of condensers connected in parallel) of such capacity that the charge and discharge effects in the artificial-line circuit may be made to equal the charges and discharges taking place in the main-line circuit. The effect of the charge passing into the line wire through the relay coils is to produce a forward, or "marking" kick of the relay armature, while the effect of the charge passing into the condenser circuit at the same instant is to produce a backward or "spacing" kick of the armature, hence when the capacity of the condenser is correctly adjusted the disturbing effects are counterbalanced, and the line is said to have been given a capacity balance.

TIMING THE CONDENSER DISCHARGE

As the time required to charge a line is longer the greater the length of the line, it follows that the time required for the line to discharge, also varies according to the length of the line. In order to introduce the element of "time" into the condenser circuit also, it is the usual practice to place an adjustable resistance in series with each of the two condensers associated with the artificial line, as shown in Fig. 219.

The discharge of the condenser produces a current the duration and quantity of which is dependent upon the electrical properties of the circuit through which it is made to discharge.

In accordance with Ohm's law a condenser requires twice as long to discharge itself through a resistance of 600 ohms as through a resistance of 300 ohms. In order that the discharge of the condensers in the artificial line shall balance the discharge from the line conductor, it is necessary that the currents be of the same duration as well as of the same quantity. In other words, on each occasion when the two discharges take place they must have an exactly equal value and effect.

the ohmic center of the circuit may be but a hundred miles distant from one terminal of a 500-mile line. The same would be true of a circuit made up partly of copper wire and partly of iron wire, owing to the fact that in a given amount of resistance there would be a greater number of miles of copper wire than of iron wire of like gage. Also it will be found that where any considerable length of line conductor passes through a cable, that portion of the conductor may have a capacity equal to that of a much greater length of open-line wire.

These are the factors responsible for the discrepancies often noted in the amount of artificial capacity required at each terminal station, to effect a capacity balance.

The proper value of retarding resistance to have in condenser circuits of multiplex lines, as a general thing, is determined by the length of the line: the longer the line, or the greater its electrostatic capacity, the greater should be the amount of resistance inserted; for, as before stated, it requires a longer time to discharge long lines than it does short ones.

The steps which it is necessary to take to establish a static balance, in any given case will depend upon the availability of the apparatus of the set, for the purpose.

In the case of a quadruplex set, a good way to obtain a static balance is to reduce the tension of the spring attached to the armature of the neutral relay while the distant station has the short-end battery to line. Then if the circuit is "out of balance," reversing repeatedly the entire home battery will result in more or less pronounced "kicks" of the relay armature. These kicks may be silenced by adjusting the capacity of the condensers and the resistance of the retardation coils until a capacity balance has been established. Ordinarily the entire operation can be completed in less than a minute, but as it is essential to obtain a correct static balance, sufficient time should be taken in all instances to accomplish the desired end.

In balancing duplexes not equipped with differential galvanometers or neutral relays for balancing purposes, it is customary to touch the armature of the polar relay with a pencil or with the finger while the home battery is reversed, and to observe any tendency on the part of the armature to respond to the reversals. This operation may be carried on either with the distant battery to line and quiet, or with the line "grounded" at the distant station.

When the "static" balance is being taken an incorrect amount of retarding resistance is evidenced by a "kick" in one of the relay coils. If the kick cannot be eliminated by altering the capacity of the condensers, or if it simply shifts from one side to the other, altering the amount of retarding resistance in series with each condenser, thus properly "timing" the discharge, quickly remedies the trouble.

POSTAL TELEGRAPH-CABLE COMPANY'S RULES FOR BALANCING

To balance a duplex:

"1. Ask the distant station to 'ground.'

"2. Throw ground switch at home station to the left.

"3. Set the armature of the polar relay in the center by adjusting the magnets until the armature will remain on either contact, or until it vibrates freely in response to the induced currents from the line.

"4. Throw the home station ground switch back to the right, thus placing the current on the line. Take a line balance; that is, adjust the resistance in the rheostat until the polar relay again acts as it did when the line was to ground at both ends. This line balance should be tried with the home key first open and then

closed. If there is any variation in the resistance required to effect a balance, an average should be made.

"5. Take a static balance in the following manner: Move the magnet of the polar relay which is on the opposite side of the local contact point, or, in other words, the magnet on the side upon which the armature rests when the sounder is open, 1/4 to 3/8 of an inch back. Then, starting with all of the capacity inserted in the condensers, make dashes with the key and gradually reduce the capacity until the kick disappears. A variation in the adjustable resistance in the condenser circuits will sometimes aid in accomplishing this result. After removing the kick replace the magnet in its former position.

"If a balance indicator is used, take the line balance by adjusting the rheostat (see Paragraph 4) until the galvanometer needle points to zero with either open or closed key at home station."

To balance a quadruplex:

"Follow the method described for duplex up to end of Paragraph 4.

"Following this ask the distant station to cut in and dot or write on the neutral or common side. With the home keys quiet the neutral relay spring tension should be adjusted as low as it will go and still clearly produce the signals from the distant station. The home battery should then be reversed and if this makes the signals from the distant station heavier or lighter the rheostat should be adjusted until the reversal of the home battery does not affect them.

"To obtain a static balance: Ask the distant station to open his key on the common side, thus placing his short-end to the line. Close the common side key at the home station. With the distant keys quiet the neutral relay spring tension should be adjusted very low and the condensers adjusted until reversals of the home battery, no matter how rapid, do not affect the neutral relay."

THE WESTERN UNION TELEGRAPH COMPANY'S RULES FOR BALANCING

Balancing the quadruplex:

"The usual practice of balancing to the distant "ground" on quadruplex circuits is now regarded as unnecessary, owing to the presence in the circuit of the milliammeter, which admits of the balances being taken against the distant battery with less loss of time, and under conditions that eliminate all difference that may happen to exist between the ground and battery resistance."

Resistance balance:

"In taking a resistance balance, proceed as follows:

"1. Ask the distant station to close both keys which will cause the milliammeter at the home station to deflect to the left, or in what may be called a marking direction.

"2. Note the number of degrees obtained on the needle, first with your No. 1 key open, and then with it closed, the deflection in each case being taken after the needle has come to rest.

"3. While the key is in the closed position, adjust the balancing resistance

until the needle reaches a point midway between the two readings above noted, which point will represent the deflection required to secure the ohmic or resistance balance. If, for instance, the needle stands at 28° on the open key, and at 24° on the closed key, then the adjustment should be such as to bring the needle to a position that will correspond as nearly as possible with the mean of the above two readings, viz., 26°.

"It will be found that when the resistance in the artificial line is greater than that in the main line, the needle will swing somewhat deliberately in an upward or spacing direction upon closing the key. And, per contra, the swing of the needle will be in the downward or marking direction should the resistance in the artificial line be less than that in the main line."

Static balance:

"It will next be in order to take a 'static' balance, any disturbance of which will make itself evident by a sudden throw of the milliammeter needle, which will quickly jerk or 'kick' in one direction just as the key is being depressed, and in the opposite direction at the moment the key is released, the needle instantly returning to its normal or steady position after each movement of the reversing key.

"In order to avoid confusion during these balancing operations, it will be well to disregard the effects produced upon the needle at the opening of the key, and take note only of those observed at the closing thereof.

"1. If, then, upon closing the key, the needle swings or kicks in a spacing or upward direction, and then rapidly returns to its former fixed position, it will be an indication that the capacity of the condensers in the artificial or compensating circuit is not enough, and should accordingly be increased.

"2. If, on the other hand, the throw of the needle is in the downward or marking direction at the instant of depressing the key, the condenser capacity should be diminished.

"The amplitude of the swing or kick in each case will show the extent or amount of the static unbalance, the latter depending upon the difference between the strength of that portion of the current which suddenly rushes into, and charges any main line possessing electrostatic capacity, and that of the current rushing into the artificial line to satisfy the "capacity" requirements of the condenser forming part of the compensation circuit."

Retardation balance:

"If the retarding resistances in the paths of the balancing condensers are not accurately adjusted the time occupied in charging and discharging the condensers will differ from that required to charge and discharge the main line. Should this difference be very pronounced, the milliammeter will give a peculiar 'double kick' each time the key is opened and closed, this kick being readily distinguished from that due to the ordinary static unbalance, in having a decidedly more jerky and lively appearance during its exceedingly brief period of existence. It may, however, be somewhat difficult to differentiate between the two, on account of the constant vibration, to which the milliammeter needle is ordinarily subjected by induction

from neighboring wires, the effects of such interference rendering accurate reading and close observations a matter of considerable difficulty. Under such circumstances, it may be well to make the final compensating adjustments by rapidly dotting on the No. 1 key, while making such alterations of the capacity—and particularly of the timing or retardation resistances—as will cause the needle to show the least amount of disturbance as a result of the changes thus made."

Approximate balances:

"An absolutely perfect balance cannot be secured until the needle ceases to be influenced by the operations of the reversing key, the steady condition of the needle denoting that an equality of potential (upon which the bridge principle depends) has then been duly established or, in other words, that the pressures exerted by the out-going current at opposite ends of the 'bridge'—in which the milliammeter and polar relay are placed—are equal in magnitude and oppositely directed, thus producing a null effect upon both of those instruments.

"An absolutely perfect balance being somewhat difficult of attainment—especially when the time involved is an important consideration—it is only necessary as a rule to obtain a good working balance, that is, one in which the clearness and legibility of the in-coming signals are practically unaffected by the out-going current.

"It should not be necessary in most cases to call in the aid, and await the appearance of any traffic or repeater chief at a distant station for the purpose of restoring a balance, which can usually be effected by suitable 'snap-shot' adjustments calculated to meet the practical working requirements, without involving a stoppage of the circuit, or the delay incident to securing the attendance of the particular chief concerned at either the repeater or terminal office."

NOTES ON QUADRUPLEX MANAGEMENT AND OPERATION.

Difference of Balance, Pole-changer Key Open and Closed.—At times it is found that the amount of resistance necessary to have in the rheostat to balance the line resistance when the polar-side key is closed, differs from that necessary to maintain a balance when the key is open.

Since the closing of the key results in sending out currents of one polarity, say negative, and the opening of the key sends out positive currents, it is evident that the difficulty referred to is due to the presence in the main-line wire, of a current of definite polarity which has leaked into the circuit from a neighboring conductor, or to a difference of potential between the home and the distant ground connection due to earth currents. Assume for instance, that a foreign potential of 7 volts positive is impressed upon the line; in one position of the pole-changer armature 7 volts are added to the operating potential, while in the other position of the armature 7 volts oppose a like amount of the applied e.m.f., thereby causing a difference of 14 volts between "open" key and "closed" key, and as no foreign voltage affects the artificial line, the variation in pressure affects the main-line circuit only.

As a normal ground is getting to be the exception rather than the rule, these discrepancies are frequently encountered, and the usual procedure is to halve the discrepancy in resistance required to balance with key opened and with key closed.

Line Capacity too High to be Balanced with Total Capacity of Condensers.—When a quadruplex attendant finds it impossible to eliminate the *B*-side "kick" by adjusting the retardation resistances, and by employing all of the artificial capacity available, in many cases the difficulty will be found to be attributable to the fact that the line wire in use is "crossed" with another line wire, and that the other wire has been thrown out of service by opening it at each of the two terminal stations. When this is done the circuit operated has a total capacity consisting of the combined capacity of both wires, and in many cases this is greater than that of the balancing condenser: obviously, the remedy is to have the discarded wire opened on each side of the "cross" as near to the point of contact as possible, in order to reduce the superficial area of the conductor; and as a consequence correspondingly reduce the total capacity of the circuit being operated.

Whether to Raise or Lower Compensating Resistance in Order to Obtain a Balance.—In attempting to balance a duplex or quadruplex, the beginner is often in doubt as to whether the resistance of the artificial line should be increased or decreased in order to equal that of the line wire.

The older quadruplex attendants have little difficulty in this regard as they know from experience the approximate resistances of the lines in their districts and are therefore enabled to quickly move the rheostat arms into the desired positions. The younger men who have not yet had an opportunity to acquire this detail information, have to "feel" their way, as it were, in giving the compensation circuit the desired values.

One way to decide the matter is: after the distant office has upon request grounded the line, the attendant at the home station should note whether the armature of his polar relay is in connection with the open or closed contact post. If, for instance, in the open position, move the rheostat lever of the 1,000-ohm units from zero around toward the higher values until the armature of the relay moves over to the opposite contact post. The 1000-ohm-unit lever should then be moved back one point, after which the 100-ohm units and 10-ohm units should be added until an exact balance is obtained.

Negative Pole to Line on Closed Key.—In the interests of standardization and of interchangeability of sets it is well to arrange all duplex and quadruplex pole-changer circuits so that they will send out the same polarity when keys are open, and the opposite polarity when keys are closed.

The reason advanced for selecting the negative pole as the "closed" pole is that: due to the periods of rest and of inaction, pole-changer armatures are in the open position a greater length of time—in the aggregate—than in the closed position, and as current from the positive terminal of the bat-

tery is less destructive to cable insulation than that from the negative terminal, it is good economy to connect the positive battery lead to the "open" contact of the pole-changer.

LOCATING FAULTS IN DUPLEX AND QUADRUPLEX APPARATUS

Faults may develop in a duplex or a quadruplex set in one or more of a number of places. Those faults which cause entire failure generally are the easiest to locate and remedy. Faults which only partially interfere with operation of the set are more difficult to run down, and in practice are less

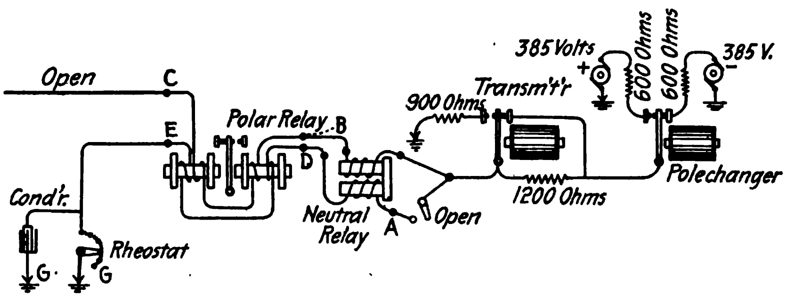


FIG. 292.—Quadruplex apparatus tests.

likely to be given due attention. A defective relay, rheostat, condenser or resistance coil may result in the unsatisfactory operation of a set without the trouble being sufficiently pronounced to justify abandoning the set as a "four-cornered" system.

The plan of set testing here described is one recently sent out by Mr. Minor M. Davis, Electrical Engineer of the Postal Telegraph-Cable Company, and which in practice has been found to give excellent results.

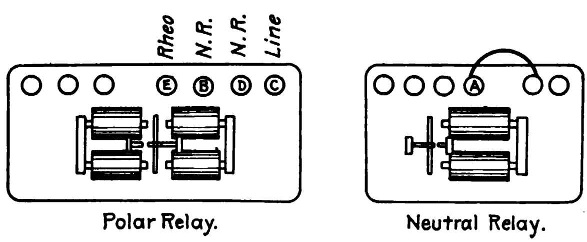


FIG. 293.—Quadruplex apparatus tests.

First, measure the total resistance of the balancing coils of a spare rheostat to make sure it is not defective. Then, at the main board, place the line wedge from the set to be tested in a grounded "flip," in series with the spare rheostat. Make the resistance of the rheostat at the switchboard 2,000 ohms. Then balance the rheostat of the set against the one at the

switchboard. After securing an ohmic balance (a static balance is not needed), allow the long-end to remain closed a few minutes to heat up the coils, and develop circuit defects should there be any. When the set has warmed up, take a voltmeter which has a single conductor cord and wedge connected to each of its terminals, to the set to be examined, and after changing the resistance of the rheostat at the switchboard to 5,000 ohms, take a new balance as quickly as possible, and proceed as follows:

Using Lower Scale of Voltmeter.—If voltage between *A* and *B* (Figs. 292 and 293) is the same as between *A* and *D*, the neutral relay is OK. If the voltage between *B* and *C* is the same as between *D* and *E*, the polar relay is OK.

Using the Upper Scale of the Voltmeter.—The voltage between *A* and *C* should equal the voltage between *A* and *E*.

TO TEST THE CONDENSERS

Using Upper Scale of Voltmeter.—If the voltage between *E* and the ground is the same when all of the condenser capacity is "cut in" as when all "cut out," the condensers are OK. If not, they are leaky.

Another way to test the condensers is to cut out all of the capacity and and open both the ground switch and the balancing rheostat. Then touch the line wedge to either battery terminal. If a condenser is short-circuited the neutral relay armature will be attracted into the closed position.

CROSSED WINDINGS IN EITHER RELAY

The introduction of a two-point switch (normally closed) in the artificial-line circuit, between the dividing point of the main and artificial lines and the neutral relay, enables the attendant to test out crossed windings in the following manner: Remove the line wire from the binding-post *C*, then open the two-point switch *A* (in the absence of a switch, the test may be made by removing the wire from the binding-post *A*). If the windings of either relay are crossed, the armatures of the relays will respond to the movements of the pole-changer key.

MEASURING THE DISTANT BATTERY

The information sought in measuring the quadruplex battery at the distant terminal station is: whether both polarities are being sent to line alternately as the pole-changer key at the distant station is operated: whether the current received from the distant battery is of sufficient strength to operate the relays, and whether the long-end and short-end from the distant station divide in the proper proportions of 3 to 1, or 4 to 1 as the case may be.

The measurements desired are, of the short-end positive current, short-end negative current, long-end positive current, and long-end negative current.

(1) Insert the double wedge connected by cord to the milliammeter in the main-line circuit, either between the line wire and main-line binding post of the polar relay, or between the line post and ground post of the ground switch.

(2) Tell the distant station to close his key on both polar and neutral sides. The reading observed in the meter will be that due to the long-end negative potential, assuming that the negative pole is to line on closed key.

(3) Cut in the home battery for a minute and tell the distant station to leave the neutral-side key closed and to open the key on the polar side. The reading observed will be that due to the long-end positive potential—assuming that the positive pole is to line on open key.

(4) Again cut in the home battery for a minute and tell the distant station to open the keys on both polar and neutral sides. The reading observed will be that due to the short-end positive potential.

(5) Ask the distant station to leave the neutral-side key open and to close the polar-side key. The reading observed will be that due to the short-end negative potential.

If the tests are made by inserting the wedge between the line wire and the main-line binding-post of the relay, the ground switch should be thrown over to the "ground" contact, and if inserted between the line binding-post and ground binding-post of the ground switch, the lever should be placed in the central position and the artificial-line opened as each reading is taken.

On account of the ever present inductive influences, there are very few lines in this country that will work satisfactorily with less than 20 milliamperes, and with a 3 to 1 proportion the long-end would need to yield 60 milliamperes.

It is of the utmost importance that the proper "ratio" should be maintained, as the successful operation of the common side relay is dependent upon the difference between operating and releasing current values.

CHAPTER XVI

DUPLEX AND QUADRUPLEX "LOCAL" CIRCUITS. LEG-BOARD, AND LOOP-BOARD CONNECTIONS

METHODS OF THE POSTAL TELEGRAPH-CABLE COMPANY

Figure 294 shows theoretically the wiring of the Postal Telegraph-Cable Company's duplex and quadruplex "local" circuits.

On the left in the center is shown the local circuits of a polar duplex, and on

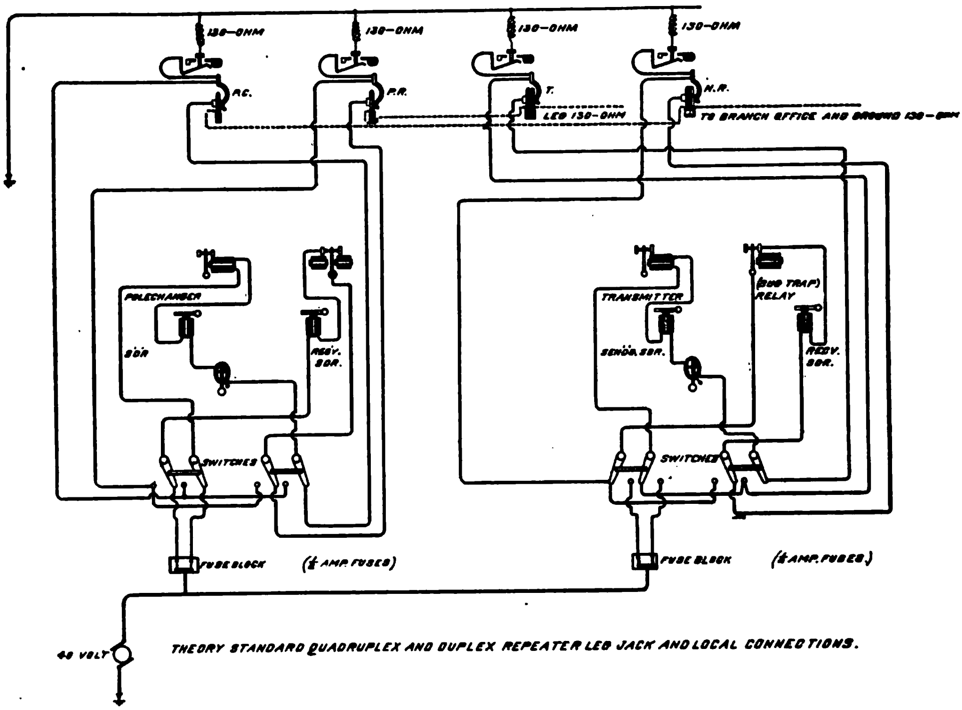


Fig. 294.

the right the local circuits of the second side of a quadruplex. The local wiring of a quadruplex would comprise all of the wiring shown in the diagram.

It will be noted that there are two six-point switches controlling the cir-

cuit arrangements of each half of the set. In each half of the set the switch on the left controls the application of battery to the sending and receiving instruments, while the switch on the right, in each case, makes it possible to extend "legs" from the sending and receiving apparatus of each half of the quadruplex, to a leg-board suitably located near the main switchboard.

The leg-board connections are shown theoretically at the top of the diagram, and it will be seen that by means of these connections, the control of the pole-changer of the duplex (or the polar side of a quadruplex) may be extended to an operating table located at a distance from the quadruplex set, or to a branch office. And, further, that the signals received by the polar relay of the duplex (or of a quadruplex) may, through the leg-board connections, be repeated directly to a sounder situated on the operating table above referred to, or to a sounder situated in the branch which may have been given control of the operation of the pole-changer of the set.

Both Local Switches to the Right.—Figure 295 is a simplified diagram showing the completed circuit from the 40 volt, or local dynamo, through the pole-changer, sounder, key, and leg-board to ground. While the local switches are to the right, the three other local circuits are connected in the same manner as the pole-changer is shown connected in Fig. 295.

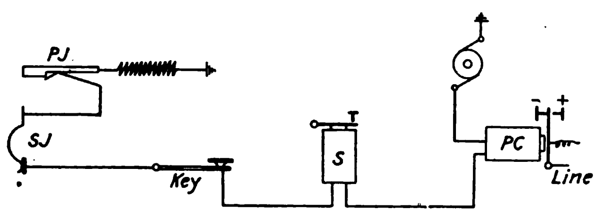


FIG. 295.—Pole-changer local circuit when levers of both table switches are moved to the right.

It will be apparent that if a separate transmitting key has its two terminals connected to the cord terminals of a double-conductor wedge, and the wedge is inserted in the spring-jack *SJ*, the extra key will have control of the operation of the pole-changer in the same way that the key of the "set" has control of that circuit, provided, of course, that the latter is kept closed.

Also, it will be apparent that the extra key may have one of its terminals connected to a single-conductor wedge, while the other terminal of the key is "grounded," in which case it is necessary that the "live" or conductor side of the wedge be placed in contact with the shoe of the spring-jack (thus removing the ground connection via the shank of the spring-jack, and the pin-jack *PJ*). In the first case, the separate key would be regarded as being "looped" in, and in the second case, as being "legged" on.

It is obvious that the loop, or the leg, whichever is employed, may be

extended to a table in the operating-room, remote from the multiplex set proper, or to a distant branch office.

Both Local Switches to the Left.—Figure 296 is a simplified diagram of the circuit conditions which exist when both switches are thrown to the left. This is the position in which the switches are placed when the set is not in use.

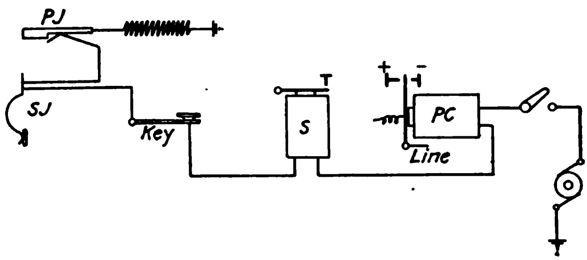


FIG. 296.—Pole-changer local circuit when levers of both table switches are moved to the left.

Local Switches Thrown "Together."—When the two local switches on one side of a quadruplex, or in a duplex, are thrown "together," that is, the left-hand switch to the right, and the right-hand switch to the left, the actual circuit connections are as indicated in Fig. 297, which provides that the attendant at the multiplex set, only, will have control of the local circuits, and that any "legs" or "loops" which may be connected into the circuit at the spring-jack *SJ* will be cut off and remain so until the right-hand switch is again thrown to the right.

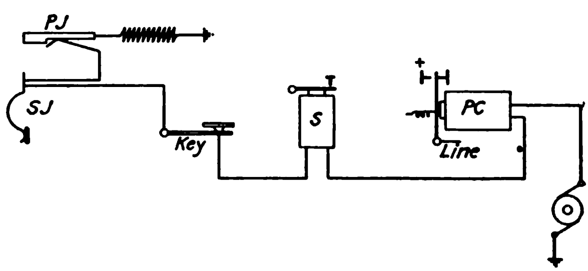


FIG. 297.—Pole-changer local circuit when levers of both table switches are thrown "together."

Local Switches Thrown "Apart."—When both local switches of a duplex or a quadruplex set are thrown "apart," as shown on the right in Fig. 294, a loop circuit is established which places the spring-jack of the "leg" or "loop" board in series with the other local connections, as indicated in Fig. 298.

This arrangement permits of connecting two grounded single circuits or "legs" and one or more loop circuits in series with the pole-changer

local, so that a number of branch offices may be given control of the latter instrument. On account of the increased resistance of the local circuit due to the added loops and legs together with the resistance of the sounders

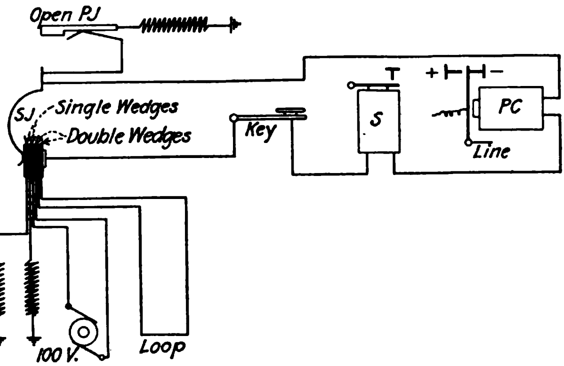


FIG. 298.—Pole-changer local circuit when levers of both table switches are thrown apart for the purpose of including an extra loop and two grounded legs.

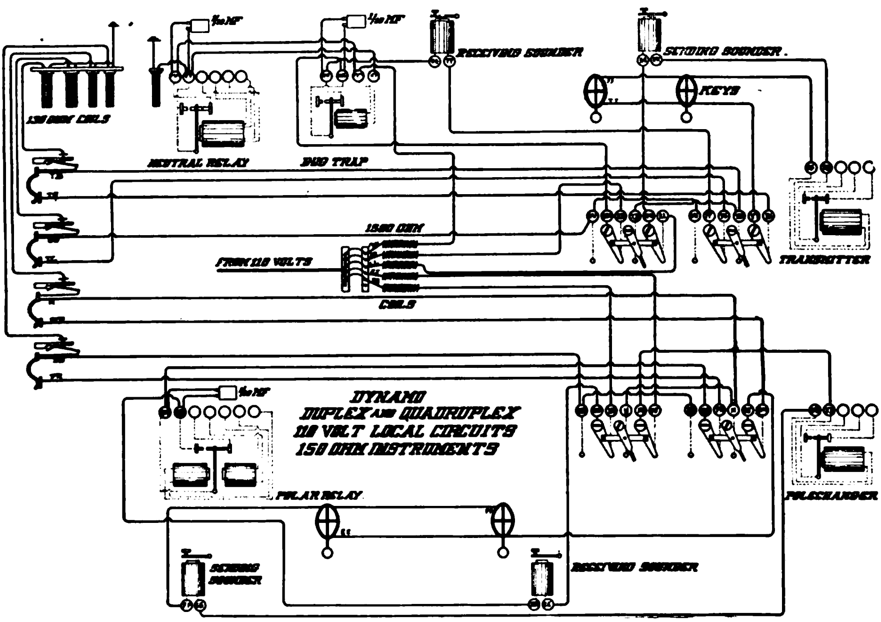


FIG. 299.

included in each additional circuit, the regular 40-volt battery is replaced with a battery of about 100 volts, both terminals of which are connected to a double-conductor wedge, for insertion in the spring-jack as shown in Fig. 298.[1]

[1] See Fig. 27a, page 43, and the description there given of intermediate battery connections.

While, in Figs. 295, 296, 297 and 298 the local wiring and loop-board connections of a pole-changer are shown, it is to be understood that in each illustration the pole-changer might be replaced by the "transmitter" associated with the second side of a quadruplex, or by the local contacts of the polar relay, or of the bug-trap relay, the latter representing respectively the receiving circuits of the polar side and common side of the quadruplex.

Figure 299 shows the actual binding-post connections of the duplex and quadruplex where 110-volt potentials, and 150-ohm local instruments are employed. Where 40-volt potentials are employed the 1,500-ohm coils are omitted, all other connections remaining the same.

Figure 300 is a photographic reproduction of a leg, or loop switchboard in one of the Postal Telegraph-Cable Company's offices. Two sections of loopswitch are shown in the left half of the photograph. It may be seen

FIG. 300.—Two sections of a "Postal" loop board.

that at the extreme upper edge of each board there is a row of pin-jacks, and immediately underneath a row of spring-jacks, then, in order, two rows of pin-jacks, a row of spring-jacks, two rows of pin-jacks, a row of spring-jacks, followed by six rows of pin-jacks in the vertical back-board, and six rows of pin-jacks in the shelf panel underneath.

Figure 301 shows in skeleton the connections and conductor assignments of the various pin-jacks and spring-jacks of this loopswitch in the order named.

WESTERN UNION QUADRUPLEX LOCAL AND LOOPSWITCH CONNECTIONS

Figure 302 shows a diagram of the local circuits and loopswitch connections of a duplex, or polar side of a quadruplex, as arranged in Western Union service.

With the switch levers in the positions shown, it is evident that the loop extending to the operating table in the main operating-room, or to a branch

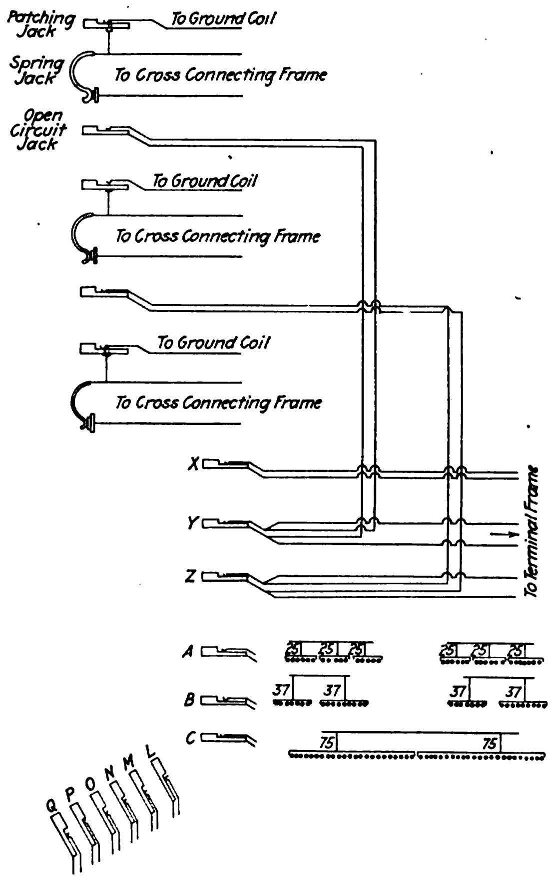


FIG. 301.—Spring-jack and pin-jack wiring of a loop board.

office has been cut off, in order that the quadruplex attendant alone may have control of the apparatus, for the purpose of balancing, etc.

Figure 303 shows the positions of the local switches after the balance has been taken, and the circuits cut through to the operating room or to a branch office. The connections are those of a polar duplex or of the polar side of a quadruplex.

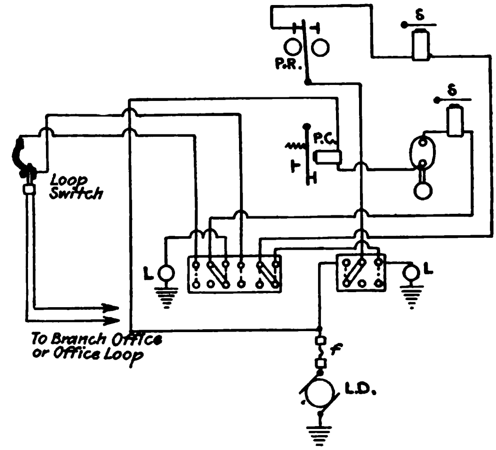


FIG. 302.—Western Union loopswitch connections.

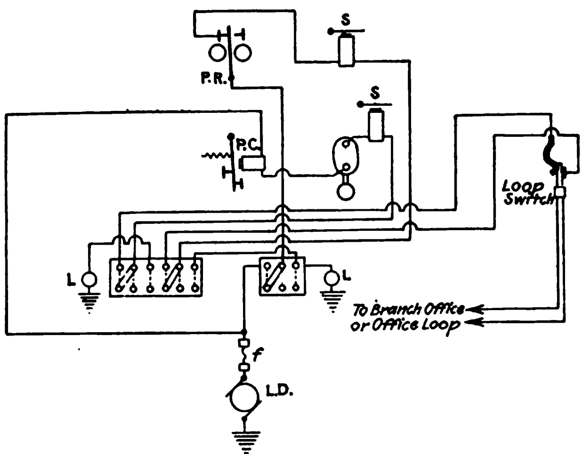


FIG. 303.—W. U. loopswitch.

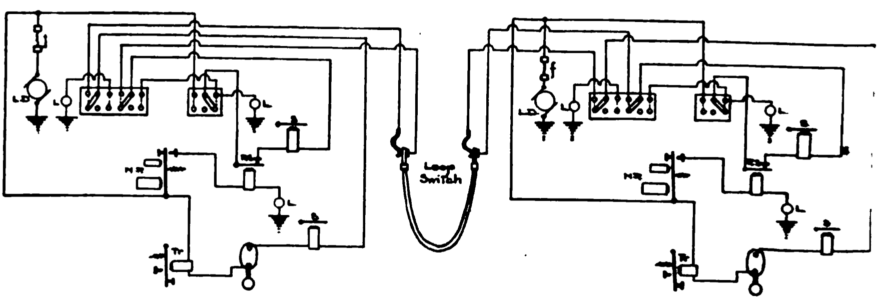


FIG. 304.—W. U. loopswitch connections for interconnecting multiplex sets.

Figure 304 illustrates the positions of the local switches for connecting the common side of one quadruplex set to the common side of another quadruplex set for the purpose of repeating. A double conductor cord with a double wedge at each end serves to connect the two sets together through

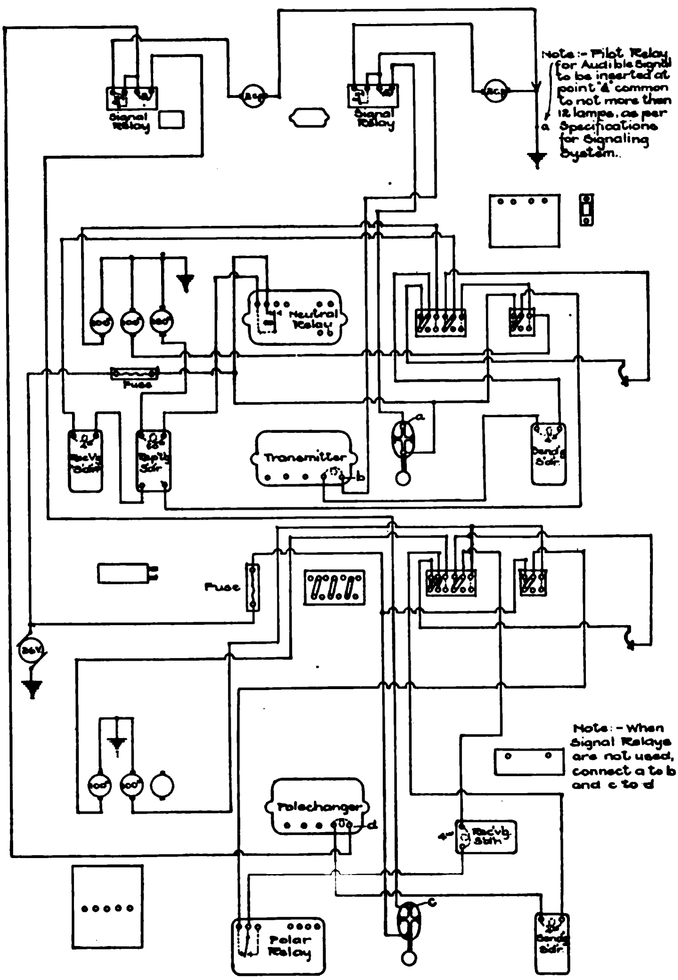


FIG. 305.—Instrument local circuit connections, W. U. quadruplex.

the medium of the proper spring-jacks in the loopswitch. In this case the positions of the switch levers are such that the neutral relay of each set controls the operation of the transmitter of the other set.

Figure 305 shows the instrument binding-post connections of the local circuits and loopswitch wiring.

OPERATING TABLE AND BRANCH-OFFICE WIRING

Figure 306 shows five loops leading from a main switchboard, each loop connected to an operating set at a table in the main operating-room or in a branch office, in each case arranged to meet different requirements.

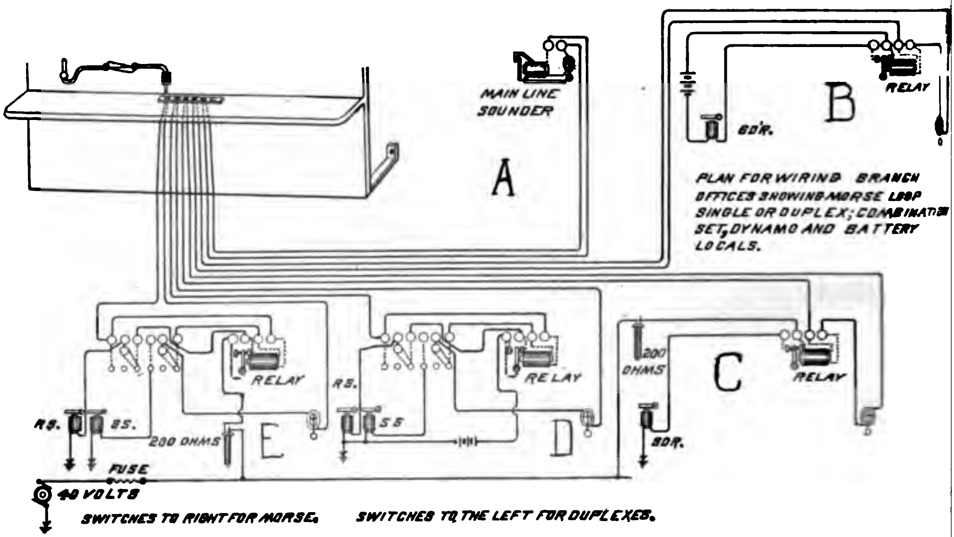


FIG. 306.—Operating table and branch office wiring.

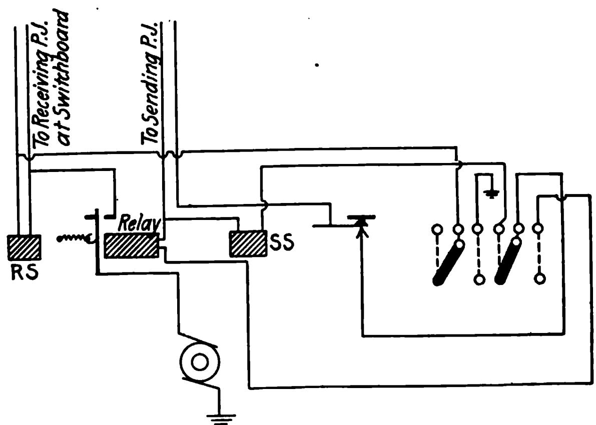


FIG. 307.—Branch office instrument arrangement for either single or duplex working, employing two loops to main office.

At *A* a loop is connected to a main-line sounder and key for single-line operation only.

At *B* single-line operation only is provided for, but in this case a relay in

the line circuit operates a sounder locally by means of gravity battery connected through the local contact points of the relay.

At *C* the arrangement is the same as at *B* except that the current to operate the sounder is obtained from a dynamo instead of a gravity battery.

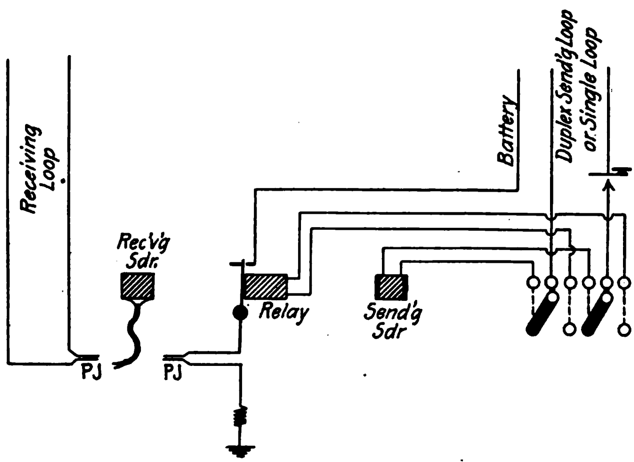


FIG. 308.—Branch office wiring for single or duplex working.

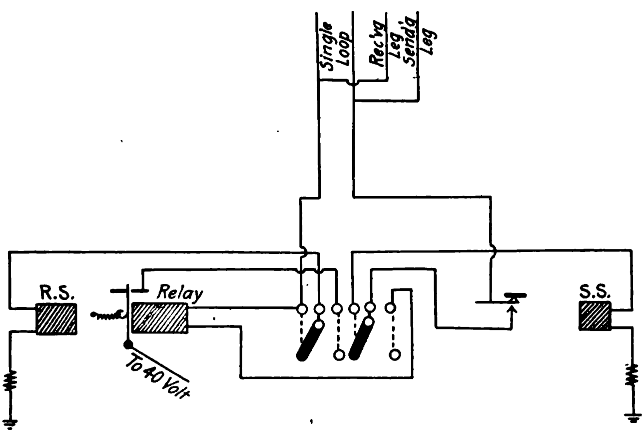


FIG. 309.—Branch office instrument arrangement for either single or duplex working, employing one pair of conductors to the main office.

At *D* provision is made for either duplex or single operation, employing gravity battery to operate the sounder when the line is worked single. The switch is thrown to the right for single, and to the left for duplex operation.

At *E* the arrangement is the same as at *D* except that dynamo current is used to operate the sounder when the set is being used for single-line opera-

tion. In each case *SS* signifies "sending sounder," and *RS* "receiving sounder."

Where dynamo current is employed for the operation of sounders at branch offices it is customary to run a local-battery main from the central office to the branch office for the purpose.

There are in use a number of methods of branch-office wiring, all of which provide for single or duplex working, simply by shifting the position of the levers of a six-point switch. Fig 307 shows an arrangement of circuits which may be employed where a sending loop and a receiving loop extend from the main to the branch office. Moving the switch levers to the right makes possible the use of the "sending" loop for single-line operation, while moving

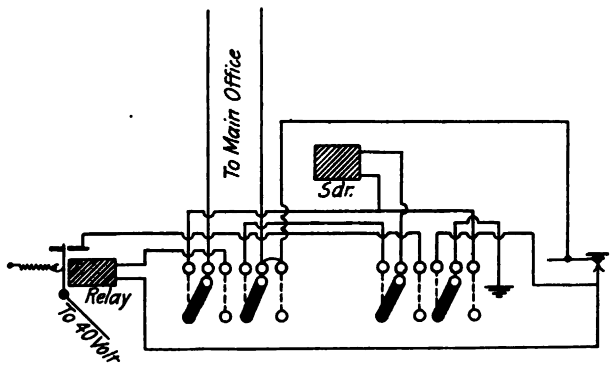


FIG. 310.—Branch office arrangement for single or duplex working, using two 6-point switches.

the levers to the left provides for duplex operation by utilizing both loops; the one on the right including the key and one sounder for transmitting purposes, and the sounder on the left serving as a receiving sounder. In the diagram the wiring at the branch office only is shown.

Figure 308 shows a similar arrangement, and which accomplishes the same purpose. The receiving sounder has attached to its terminals a flexible double-conductor cord to the outer end of which is connected a double plug for insertion into the pin-jack to the right when the relay is connected into a single line, and into the pin-jack on the left when a duplexed circuit is to be operated from the branch office.

Throwing the switch to the right provides for single-line operation, while the reverse movement provides for duplex operation.

Figure 309 shows an arrangement using one switch and one pair of conductors between the main and branch offices. At the main office a "half-tap" is made connecting each side of the loop, on the one hand to a double pin-jack in the main board, and on the other to two separate single pin-jacks in the leg-board. As in the other methods illustrated, moving the switch

levers to the right provides for single-line operation, while moving them to the left provides for duplex operation.

Figure 310 depicts an arrangement of circuits in which two 6-point switches are employed at the branch office, and where one pair of conductors extends between the main and branch offices. Throwing the levers to the right provides for single-line operation, while placing the switches in the opposite position, as shown in the diagram, provides for duplex operation.

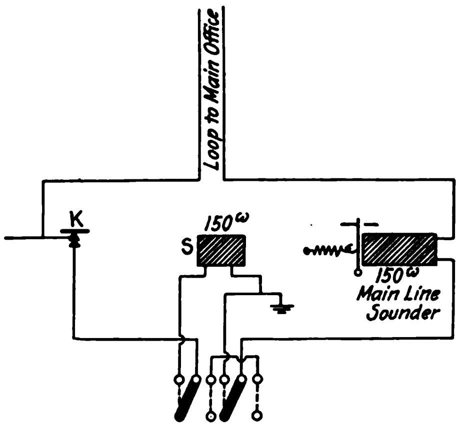


FIG. 311.—Branch office arrangement for single or duplex working, where 110-volt local current is used.

Figure 311 shows a "combination" set for single or duplex service, in use where 110-volt local battery is employed for the operation of local circuits. At the main office, 1,500-ohm resistance coils are inserted in each 110-volt battery lead, and at both main and branch offices 150-ohm instruments are used. When the switch is in the position shown in the diagram the circuit is arranged for duplex operation, and when thrown to the right the branch-office ground connection is removed and the main-line sounder and transmitting key are connected in series in the loop extending to the main office so that the set may be used for single-line operation.

CHAPTER XVII

BRANCH-OFFICE ANNUNCIATORS. GROUPING OF WAY-OFFICE AND BRANCH-OFFICE CIRCUITS—NEEDHAM ANNUNCIATOR. OFFICE SIGNALING SYSTEMS FOR MULTIPLEX CIRCUITS. BELL-WIRES. MAIN-LINE CALL BELLS, SECOND SIDE OF QUADRUPLEX. SELECTORS

When main-line circuits are extented through to broker offices, newspaper offices, or branch commercial offices by means of loops from the main office, it is not always practicable to have attendants at the latter office to constantly observe the operation of such circuits in order to be on hand when interruptions occur. In order to provide branch offices with a means of calling an attendant at the central office to the circuit in trouble, it is customary to maintain at the latter office a "bank" of annunciators through the windings of which the various loops may be connected. The annunciator may be operated by pressing a contact button or closing a switch at the branch office, resulting in the release of the shutter or tablet of the annunciator connected into that particular circuit. The falling of the shutter exposes to view a marker bearing the name of the brokerage firm, the number of the wire, or the call of the office signaling for attention. As usually arranged the shutter in falling closes a local circuit which includes an electric bell, a miniature incandescent lamp, or both, in order to insure quick response at the main office.

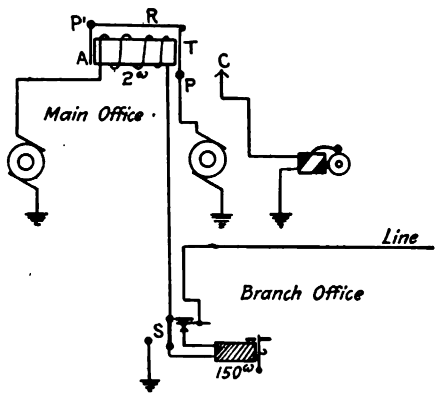


FIG. 312.—Branch office signaling annunciator.

A simple arrangement sometimes employed is illustrated theoretically in Fig. 312, which shows an individual "straight-wound" magnet annunciator at the main office, having a resistance of 2 ohms. The tablet T is pivoted at P, while the armature A is rigidly connected at P' with a light rod R extending along the top of the magnet, and fitted with a hook, which, due to gravity, retains the tablet in the upright position when the annunciator magnet is not energized sufficiently to attract its armature. As the 2-ohm annunciator mag-

net requires at least five times as much current to attract its armature as the 150-ohm relays in the circuit require for their operation, it is plain that as long as the ordinary current strength obtains in the circuit the armature of the annunciator will not be attracted. Should the branch office, however, move the lever of the switch *S* into contact with the ground connection, the total resistance presented to the battery will be greatly reduced with the result that the current in the circuit instantly builds up to a strength sufficient to energize the annunciator magnet, causing its armature to be attracted, releasing the tablet *T*, which, coming into contact with the metal terminal *C* closes a local circuit which includes an electric bell. At the branch office the switch *S* needs only to touch the ground contact momentarily to accomplish its purpose. The attendant at the main office upon hearing the bell connects his test set into the proper circuit and restores the tablet to the upright position.

THE DIFFERENTIAL ANNUNCIATOR

Figure 313 shows the actual main-office and branch-office connections of an arrangement extensively employed by the Postal Telegraph-Cable Company

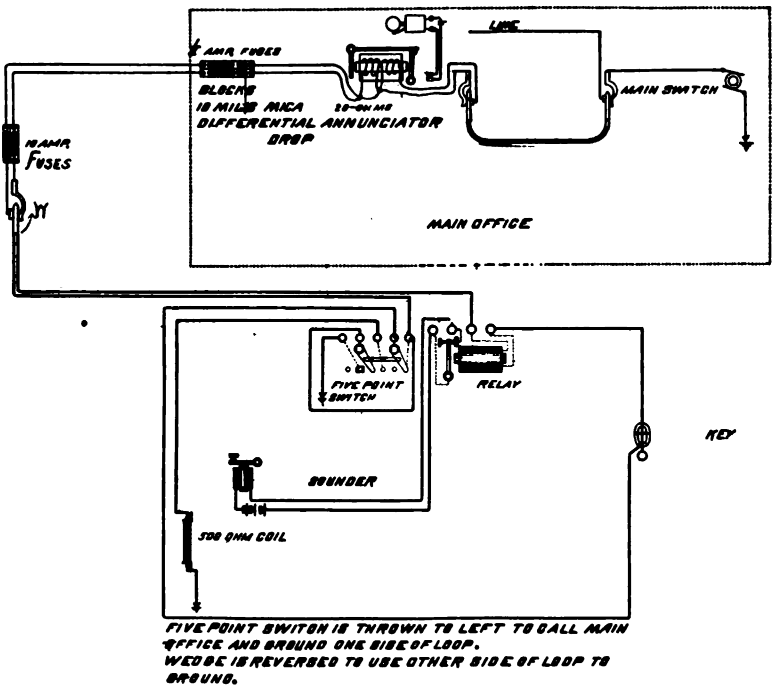


FIG. 313.—Differential annunciator.

in which the annunciator at the main office has two identical windings; one in each side of the loop.

To operate the device, the levers of the five-point switch at the branch office are moved to the extreme left position and back again to the right. It is apparent that this operation momentarily grounds one side of the loop thus permitting a greater volume of current to flow in one winding of the annunciator than flows through the companion winding, resulting in the attraction of the armature and the release of the tablet.

Should trouble develop in the loop, it is apparent that by placing the levers of the five-point switch to the left, one side of the loop may be worked to a ground at the branch office. Reversing the wedge *W* in the spring-jack at the branch office permits of using either side of the loop in series with the branch-office relay and key.

ANNUNCIATOR-BOARD CONNECTIONS

Figure 314 shows the magnet and pin-jack connections of one annunciator unit at the main office where the differential system is employed. Pin-jacks

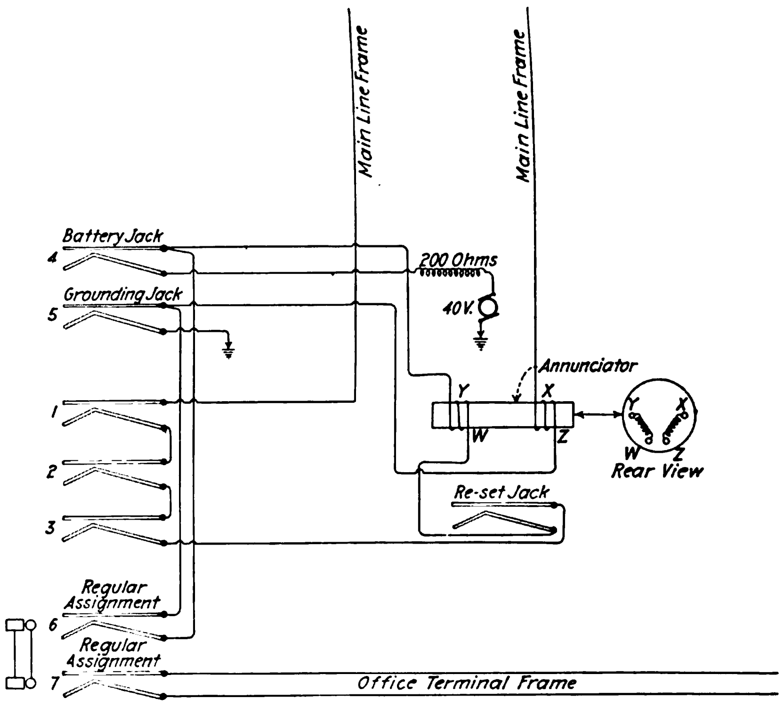


FIG. 314.—Annunciator-board connections. Differential annunciator.

1, 2, and 3 are normally closed, and are used to connect test Morse sets into the circuit, or to connect additional loops in series with that particular line by means of double-conductor plugs attached to flexible cords. Pin-jacks 4 and 5 are normally open, and are used for applying battery or ground con-

nections at the annunciator board as desired. Pin-jacks 6 and 7 are located close together so that a comparatively short cord may be used to make the regular assignment connection between a particular branch-office loop and a particular main-line wire. The re-set pin-jack shown beneath the annunciator magnet is the one usually availed of by the annunciator attendant to connect his Morse set into the circuit when he is signalled in. Insertion of the plug in the re-set-jack automatically restores the tablet (not shown) to the upright position.

GROUPING WAY-OFFICE AND BRANCH-OFFICE CIRCUITS

In nearly all large telegraph offices there are many individual circuits having one or more offices connected therein, which do not have a sufficient amount of business passing over them to justify the continuous attention of an operator on each such circuit, at the main office. The traffic problem here presented consists in giving reasonably prompt service to the various outlying offices with the minimum number of operators at the main office.

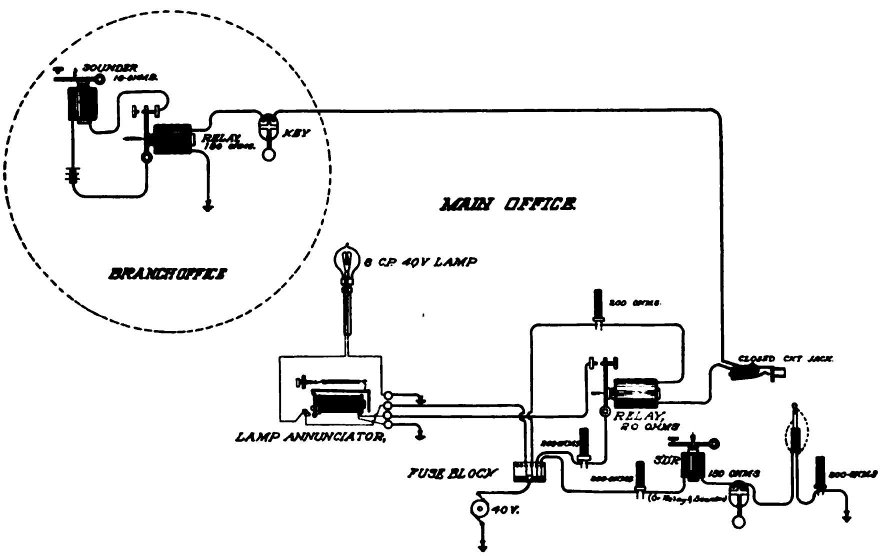


FIG. 315.—Branch office signaling arrangement for concentrated circuits.

There are several somewhat different circuit-concentrating methods employed for the purpose of meeting these conditions, all of which are identical in certain respects.

In the service of both the Western Union, and the "Postal" companies it is customary to mount a number of annunciators along the center of an operating table, each annunciator being connected in circuit with a separate

branch office, or short line wire, and so located with respect to the position of the operator, that one man can conveniently answer calls upon a number of circuits, similarly to the manner in which a central telephone-office operator can answer calls from a number of telephone stations, that is, by inserting a plug connected to a flexible cord into a pin-jack which is connected in series with the line upon which the calling office is located. The flexible cord in turn being connected with a common operating set—in this case a Morse relay, sounder and key.

Figure 315 shows a method in use at some offices. If the circuits are carefully traced it will be seen that when the branch-office operator desires to attract the attention of the main-office attendant, the only action necessary is to momentarily open the branch-office key. This results in the armature lever of the 20-ohm pony relay making connection with its back-stop long enough to permit current from the local dynamo to actuate the annunciator, the shutter of which falls and closes the lamp circuit, the lamp remaining lighted until the shutter is restored to the normal position by the main-office attendant. The latter then inserts the plug in the closed-circuit jack, thereby connecting the 150-ohm instrument into the circuit, enabling the branch office to transact business in the usual manner. After the message has been received the main-office attendant withdraws the plug and inserts it in the closed-circuit pin-jack of another similar circuit, the annunciator of which has in the meantime signalled a call from another office.

The number of circuits which may be satisfactorily attended to by one operator depends upon the ability of the operator, and upon the frequency of calls upon the various circuits. In some instances one operator can safely handle a dozen or more circuits, while in other cases one or two circuits will keep one man busy. One great advnatage derived from this arrangement is that an operator can attend to a number of circuits without having to move around from table to table as was necessary in the city line and way-wire departments before the annunciator systems were introduced.

THE NEEDHAM ANNUNCIATOR

A very satisfactory annunciator, the invention of Mr. J. T. Needham, and used extensively by the Postal Telegraph-Cable Company, is illustrated in Fig. 316, which shows both main-office and branch-office wiring. At the main office the annunciator is connected directly in the line—no pony relay being required. The annunciator is mounted in the center of the operating table, and has one closed-circuit pin-jack facing each side of the table so that the call may be answered from either side. Opening the key at the branch office results in demagnetization of the annunciator magnet, permitting a spring attached to the armature to move the "semaphore" into the signaling position. Insertion of the double plug of the Morse set

into either pin-jack mechanically restores the semaphore to the non-signaling position. As usually arranged, the semaphore in turning causes a local circuit to close, which lights an incandescent lamp, and, as the lamp remains lighted until the plug attached to the flexible conductors of the Morse set is inserted in the annunciator pin-jack, the number of lights burning at one time in any division constitute an unquestionable indication of the number of unanswered calls.

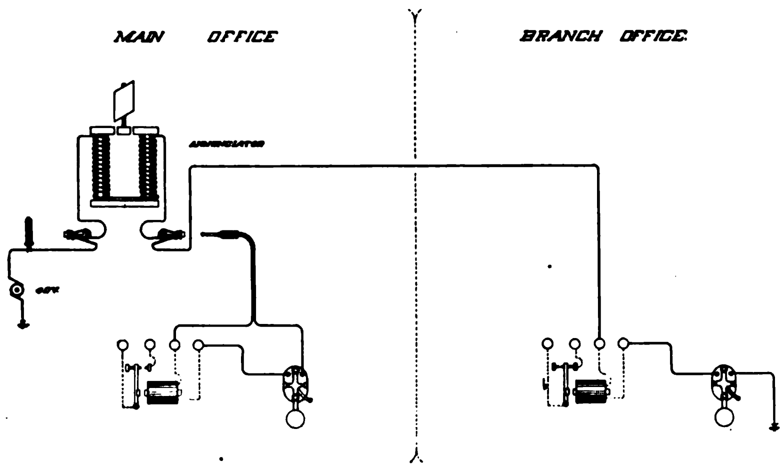


FIG. 316.—The Needham annunciator for concentrated circuits.

OFFICE SIGNALING ARRANGEMENTS FOR DUPLEX AND QUADRUPLEX CIRCUITS

At the present time it is the usual practice to concentrate all duplex and quadruplex equipment in a department, removed to a greater or less distance from the tables at which the operators sit while sending or receiving messages; the connections between the multiplex sets and the operating tables being made through the loopswitch as previously explained. An operator working on a quadrulpex circuit may be located at a table situated 100 ft. or more; distant from the quadruplex apparatus proper. When trouble of any kind develops in the operation of the circuit, it is necessary that the operator have at hand a means of signaling to the quadruplex attendant for attention.

The arrangement used for this purpose by the Postal Company is depicted theoretically in Fig. 317. The annunciator mounted on a shelf or table as a component part of each duplex and quadruplex set, is connected in series with the pole-changer magnet winding as shown in the diagram. The ampere-turns of the winding of the annunciator magnet are of such value that the normal current strength obtaining in the circuit is not sufficient

to cause the armature of the annunciator to be attracted. When, however, the operator depresses the push-button it is evident that the current strength will be raised considerably, as now a 50-ohm path to ground has been sub-

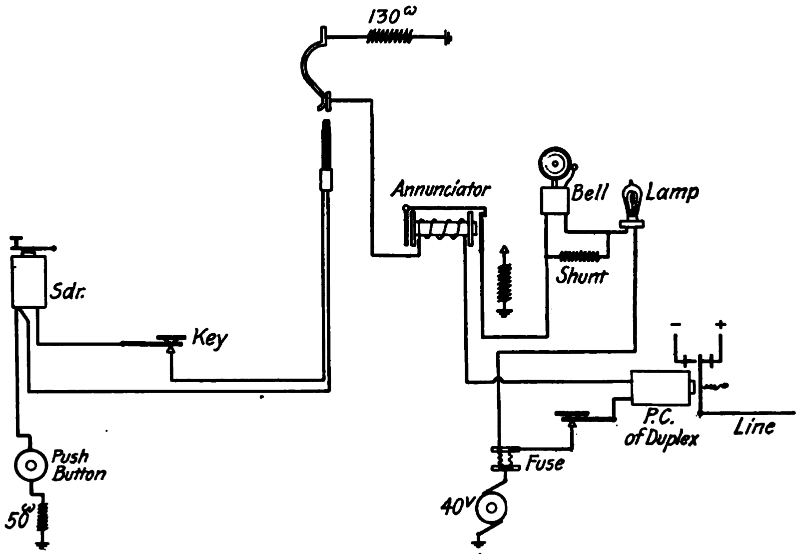


FIG. 317.—Signaling arrangement between operating table and multiplex department.

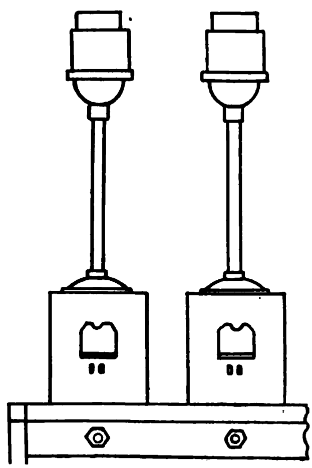


FIG. 318.—Form of multiplex annunciator.

stituted in place of the 150-ohm path to ground via the 20-ohm sounder and the 130-ohm resistance coil at the loopswitch. Obviously, the retractile spring attached to the armature of the annunciator must be adjusted so that the normal current used to operate the pole-changer will not actuate the

annunciator. The arrangement here considered is quite similar to that described in connection with Fig. 312.

Figure 318 illustrates the actual appearance of this type of lamp annunciator. Two units are shown mounted side by side.

WESTERN UNION SIGNALING SYSTEM FOR DUPLEX AND QUADRUPLEX CIRCUITS

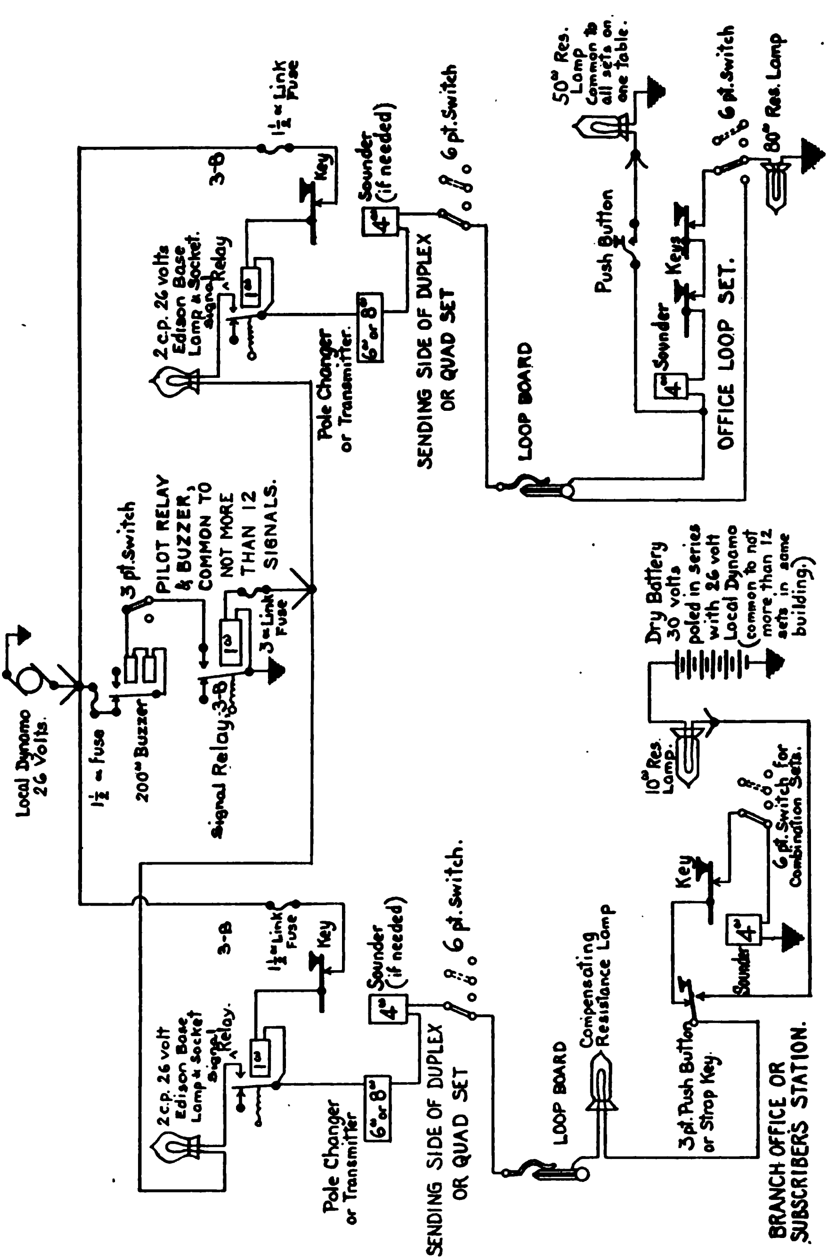
In principle this system is the same as that previously described, but certain accessory devices are added which change somewhat the appearance of the apparatus.

Figure 319 shows the circuit arrangements where the system is used for branch office signaling on duplex or quadruplex circuits, also when used for signaling purposes between operating tables and the quadruplex department of main operating-rooms.

Pressing a button at the distant operating table causes a lamp to be lighted at the quadruplex set. In case the circuit is in need of attention from the wire chief or the quadruplex attendant, the operator presses the button thereby causing both a visible and an audible signal to be registered at the quadruplex table. If the circuit is not completely interrupted, operation may be continued, as the light will not be extinguished until the attendant answers at the multiplex set. At the instant the attendant opens his key in order to learn the occasion for the signal, the light is automatically extinguished. When the circuit has been made good and the key at the quadruplex set closed, the lamp is again ready to respond to subsequent signals from the operator working the circuit.

The operation of this arrangement is dependent upon a 1-ohm "pony" relay of special design. Where "loops" or "legs" are directly connected to a duplex or to one side of a quadruplex, one of these relays is connected in the pole-changer, or transmitter local circuit. The relay is not actuated by the regular current of about 250 milliamperes, but its armature is attracted when the current is raised to a strength of 350 milliamperes, which strength obtains when the push-button at the operating table is depressed. When an operating-room loop is connected to the set the increase of current strength is accomplished by presenting a path to ground via the push-button, which has a considerably lower resistance than that of the regular circuit via the 80-ohm lamp.

In order to operate the signal from a branch office or a broker's office, a 3-point push-button is employed, which applies an additional battery for the purpose of momentarily increasing the value of the current flowing in the circuit. The increased current strength is sufficient to cause the signal relay to attract its armature, and this in turn closes the lamp circuit. It will be seen that while the armature of the signal relay is in the closed position



SIGNALING CIRCUIT FOR CALLING IN QUAD & DUPLEX ATTENDANTS.

FIG. 319.—Western Union arrangement.

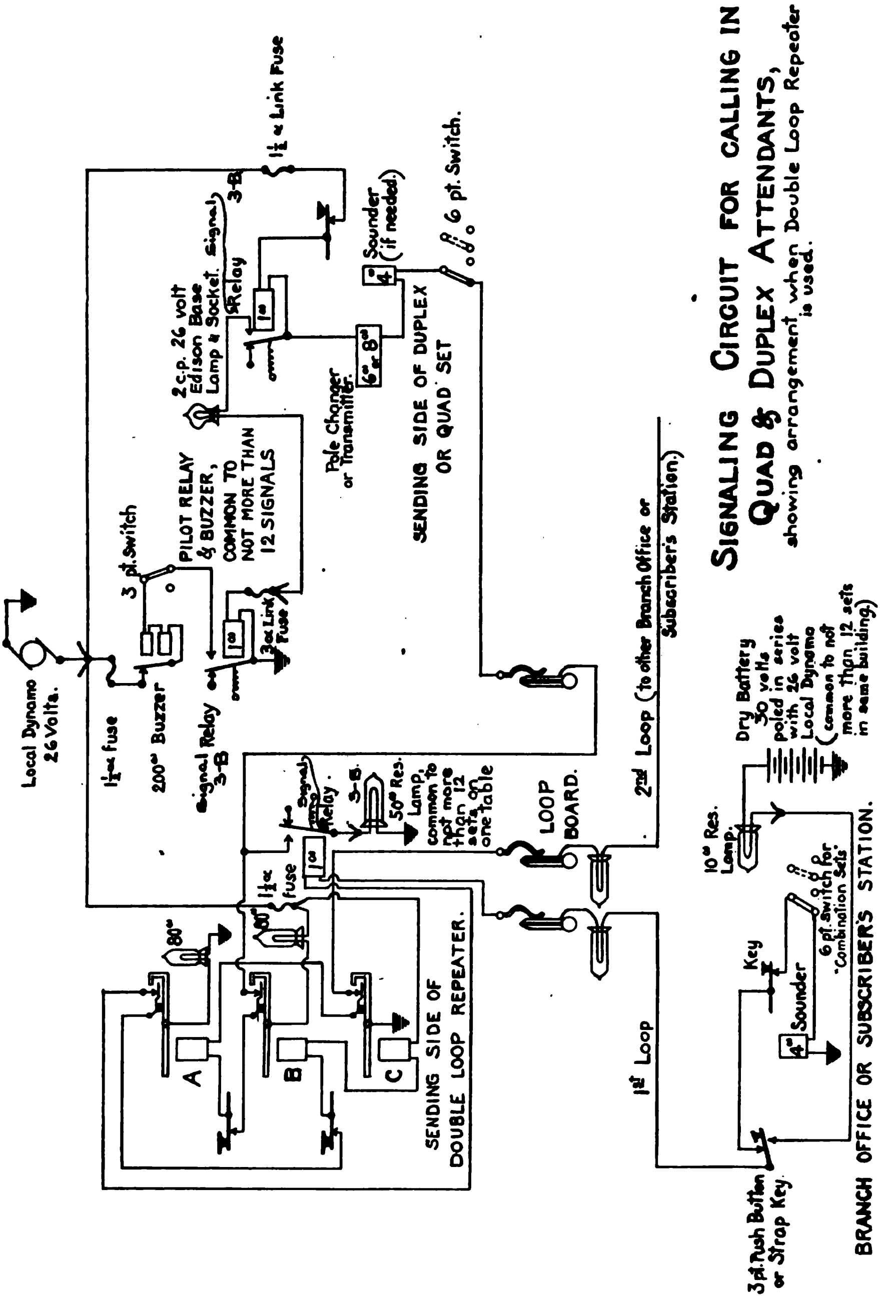


FIG. 320.—W. U. arrangement.

it will remain there as long as the key at the quadruplex set remains closed, as, now, the 350 milliamperes current flowing through the lamp circuit (from the 26-volt dynamo) also traverses the winding of the signal relay, and, being of the required strength, holds the armature in the closed position. The lamp, therefore, remains lighted until the quadruplex attendant comes to the set and opens his key in the act of communicating by Morse with the operator working the circuit, for the purpose of learning the nature of the difficulty. At the instant the key is opened the circuit from the 26-volt dynamo is interrupted, resulting in the release of the armature of the signal relay, which in turn opens the lamp circuit and causes the light to be extinguished.

Figure 320 shows the signaling circuits as arranged when sending and receiving legs are connected to the multiplex set through a double-loop repeater. In this case the repeater apparatus includes one of the special relays which repeats into the multiplex sending circuit the signal produced by pressing the push-button in the sending leg connected through the double-loop repeater.

MAIN-LINE CALL BELLS, USING SECOND SIDE OF QUADRUPLEX

In order to expedite circuit changes at terminal offices, it is quite often advisable to maintain "bell" wires between the terminal offices of the various

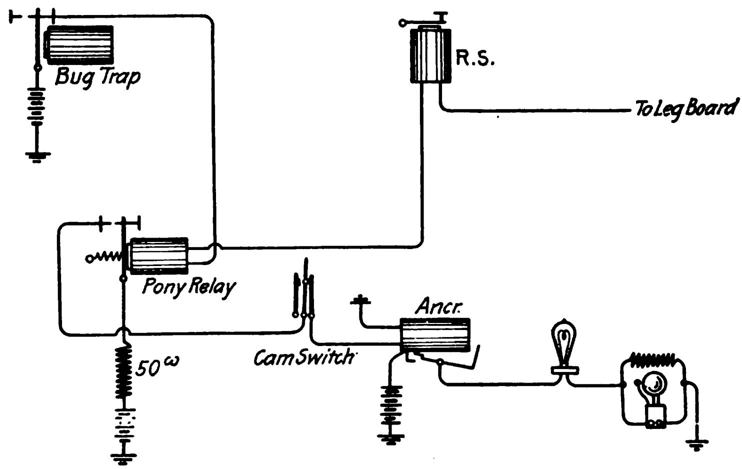


FIG. 321.—Main-line call bell, second side of quadruplex. Opening the "B" side key at the distant station operates the annunciator.

wire districts so that wire chiefs may have an ever ready means of communicating with each other without being required to send service messages over wires carrying regular traffic, or without having to set up a special circuit for the purpose on each occasion that such communication is necessary.

To maintain such communication between the various terminal offices it is the usual practice to "quad" circuits over which duplex service only is to be maintained, in which case the polar side is assigned to carry regular traffic, while the neutral side is used for bell-wire purposes. At Chicago, for instance, the eastern wire chief may have a bell wire to Detroit, Cleveland, Indianapolis, Columbus, etc., or to each terminal office with which he makes wire changes, where quadruplex equipment is available for the purpose.

Figure 321 shows theoretically the local circuit arrangements necessary for the operation of the bell and lamp. The polar side of the quadruplex used is operated from the long-end potentials at each end of the circuit, that is, the neutral side keys at each station are normally closed, which provides that the neutral relays and bug-trap relays also, at each end will remain closed normally. The diagram shows the bug-trap connections of the quadruplex set at one station only. To operate the signal, the only

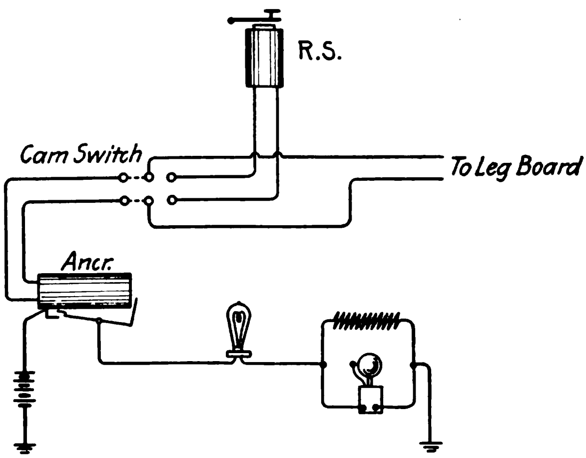


FIG. 322.—Main-line call bell, second side of quadruplex. Closing the "B" side key at the distant station operates the anunciator.

action necessary on the part of the wire chief at the distant station is to open the transmitting key on the neutral side, thereby placing the short-end battery to line. This results in the armature tongue of the pony relay making contact with its back-stop, permitting current from the local battery to energize the annunciator magnet which raises the indicator into view, at the same time closing the lamp and bell circuit. The wire chief at the station called, in responding, holds the center lever of the cam switch to the left so that the annunciator will remain silent while the conversation continues. The call is answered by means of a key which controls the operation of the transmitter of the quadruplex set, and the conversation is carried on in the

usual manner—by Morse—over the neutral side without interfering with the traffic being handled on the polar side of the quadruplex.

When the conversation is over, the center lever of the cam switch is released and returns to the position shown in the diagram, again placing the annunciator in circuit with the back contact point of the pony relay.

In practice the annunciator, lamp, bell, relay, sounder, cam switch and Morse key are conveniently mounted at the main switchboard, and by means of loopswitch connections, the neutral side of any quadruplex set may be connected thereto, so that the wire chief—without leaving his post—may signal to the switchboard attendant at any distant terminal office with which bell-wire service is maintained.

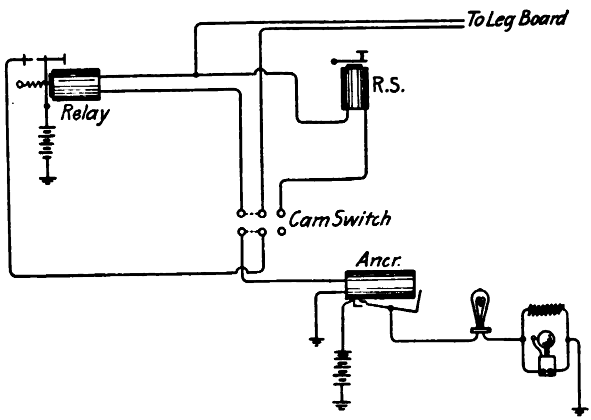


FIG. 323.—Main-line call bell for "short-end" signaling.

On short quadruplex circuits, where, ordinarily, the short-end current strength is sufficient to satisfactorily operate the polar side, the bell-wire annunciator may be operated by temporarily applying the long-end potential to the line. Fig. 322 shows the receiving loop connections where long-end signaling is maintained.

Figure 323, shows the necessary connections in those installations where the receiving side is extended from the quadruplex set to the wire chief's desk by means of a loop, the local circuits being arranged for short-end signaling.

It will be noted that the lamp does not remain lighted until the call is answered unless the signaling key at the distant station is left open, leaving the short-end battery in contact with the line. The signal, therefore, may be made intermittent or continuous as desired.

MAIN-LINE "SELECTOR" SIGNALING

Consider an important circuit made up as depicted in Fig. 324, extending from a branch office in New York City to a branch office in Kansas City, all

stations, excepting the two branch offices, having repeaters in the circuit. If delays due to wire trouble or to repeater defects are to be kept down to the lowest possible duration, it is necessary either to maintain a rider at each repeater, or to provide the branch office at each terminal with a means of "ringing in" any one or all of the repeater offices when trouble develops.

Selectors have been used on various railroads throughout the country during the past 20 years to afford train dispatchers a means of sounding a bell alarm at stations where but one operator is employed, and whose duties at times take him out of hearing of the regular Morse instrument. The

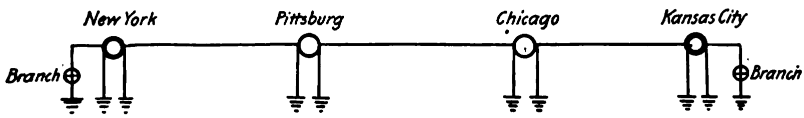


FIG. 324.—Long circuit connected through four repeaters.

selector at each station along the line responds to a particular combination of dashes made with the Morse key, or by a specially constructed call box, similar to the call boxes used as messenger calls in district messenger systems, the selector, of course, being entirely unresponsive to the opening and closing of the main-line circuit when Morse signals are being transmitted.

Within recent years selectors have been developed which may be used on metallic-circuit telephone train-dispatching circuits, without interfering with telephonic conversation, and without introducing appreciable transmission losses, but for the purposes of the present work it will be sufficient to consider only the connections necessary in applying the selector to circuits operated as single Morse lines, and as duplexed lines.

THE GILL SELECTOR

The main features of the Gill selector are a combination wheel and a time wheel which is normally held at the top of an inclined track. The operation of the selector magnet allows the time wheel to roll down the track. If the magnet is operated rapidly the wheel does not get to the end of its travel before being pushed back again. A small pin in the side of a pawl engaging the combination wheel normally opposes the combination wheel teeth near their outer points. When the time wheel falls to the bottom of the track, however, the pawl is allowed to drop to the bottom of the tooth. Some of the teeth on the combination wheel are so formed that they will effectually engage with the pawl only when the latter is in its normal position, while others will engage only when the pawl is at the bottom position. Thus innumerable permutations may be made, which will respond to certain combinations of rapid electric impulses with intervals between. The correct

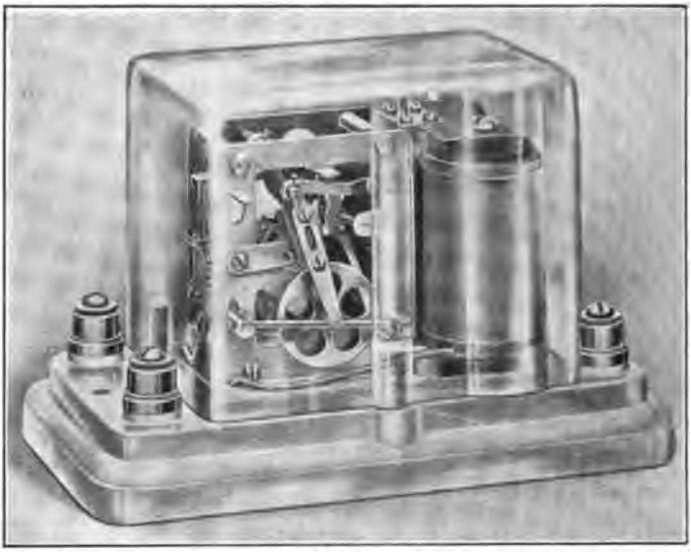


FIG. 325.—The Gill selector.

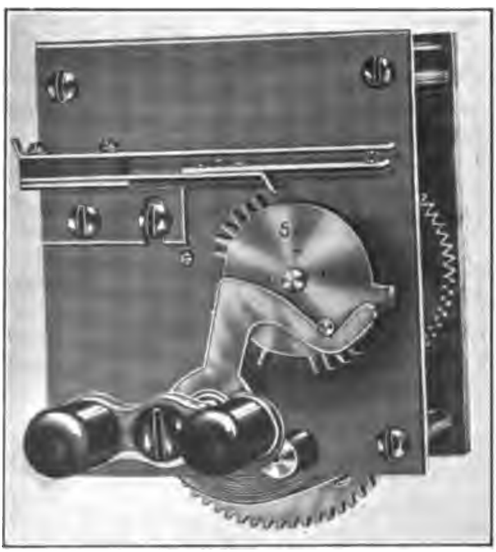


FIG. 326.—Call-box to operate Gill selector.

sequence of impulses and intervals steps the combination wheel around, so that a contact is made. All other wheels fail to reach the contact position because at some point or points in their revolution the pawl has slipped out, allowing the combination wheel to return to its initial position.

Figure 325 shows a view of the Gill selector. The mechanism is enclosed in a glass case, mounted on a porcelain base with the combination number to which the selector responds marked thereon.

Figure 326 shows a view of the call box (cover removed) which is connected around the Morse key, the combination number of the box being stamped on the handle. In order to transmit the combination over the line all that is necessary is to give the handle a quarter turn and release it.

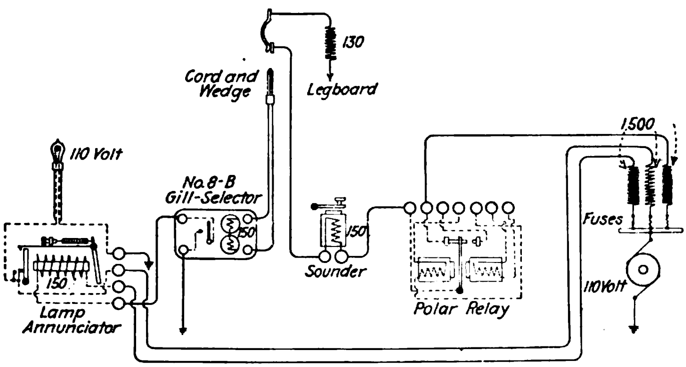


FIG. 327.—Gill selector connected into a duplexed circuit, where 110-volt local current is used.

When the main-line windings of the selector have been actuated by the correct combination of impulses the local secondary circuit is closed for a moment or two, and, where the secondary circuit includes directly a battery and a vibrating bell, the hammer of the bell will tap the gong but a few times on each occasion that the signal combination to which that particular selector responds is transmitted over the line. If the signal is to be continuous until answered it is necessary that the local circuit of the selector proper shall in turn operate an annunciator which will close a bell or lamp circuit as shown in Fig. 327. In such cases, where auxiliary annunciators are provided, the bell continues to ring, or the lamp continues to burn until the "drop" of the annunciator is reset in the vertical position.

Figure 328 shows the wiring of the selector equipment in use where 40-volt local current is employed. The main-line coils of the selector are connected to a cord and wedge so that the selector may be connected into the receiving side of any duplex or quadruplex set at the leg-board as indicated in the diagram. In practice, of course, the selector and annunciator are mounted on the same table or shelf as the multiplex equipment, and the two

wires from the selector main-line binding-posts terminate in a pin-jack located in the pin-jack panel of the leg-board, the connection being made with the spring-jack by means of a flrxible cord equipped at one end with a double plug and at the other end with a double wedge.

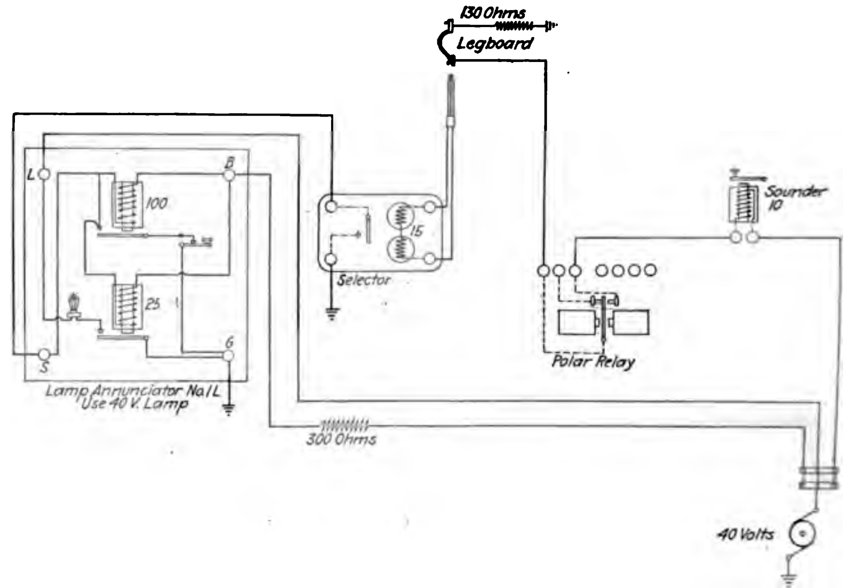


FIG. 328.—Gill selector connected into a duplexed circuit, where 40-volt local current is used.

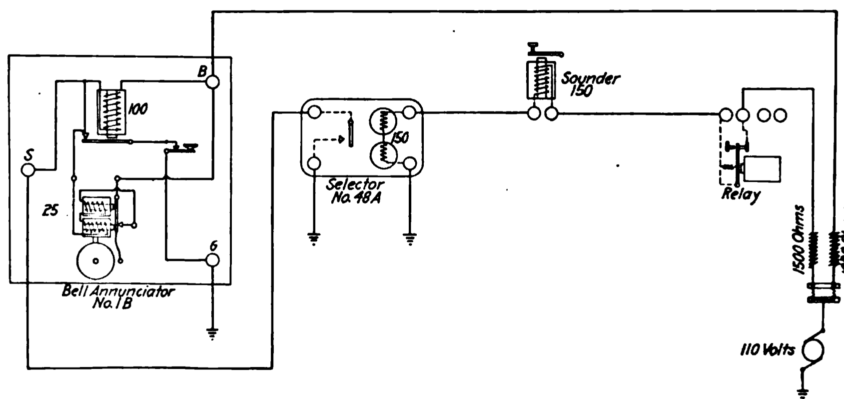


FIG. 329.—Gill selector connected into a single Morse line. 110-volt local battery.

The annunciator arrangement illustrated in Fig. 328 has a locking magnet controlling the operation of the armature which, when in the closed position, maintains the battery circuit through the lamp circuit intact after the local

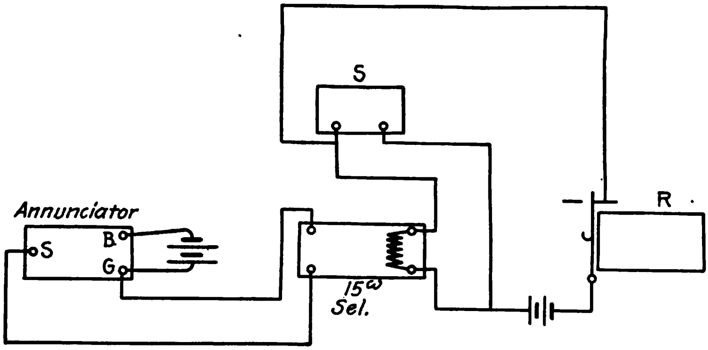


FIG. 330.—Gill selector connected into a single Morse line at a way office using gravity battery locals.

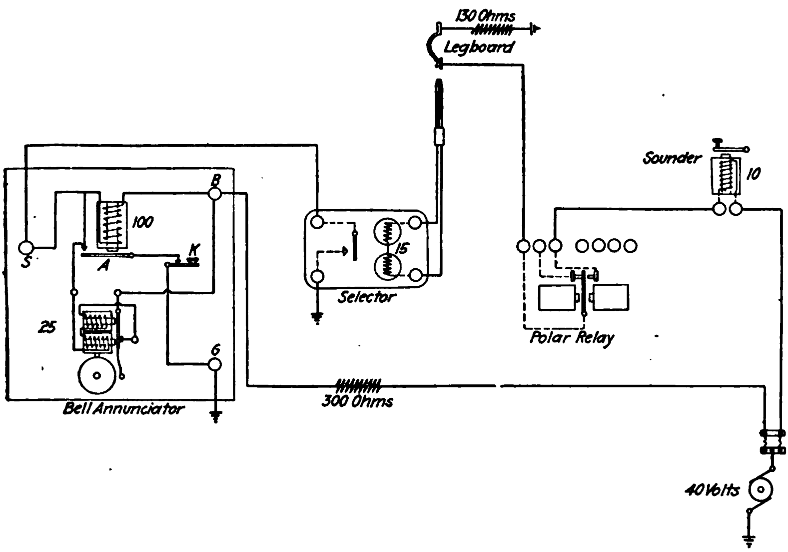


FIG. 331.—Gill selector and lamp annunciator.

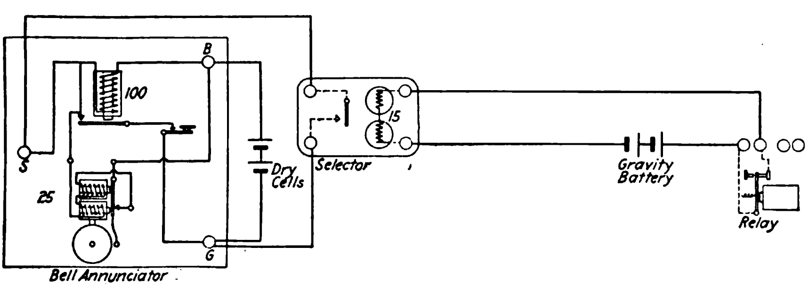


FIG. 332.—Selector connected to single-line repeater. Gravity battery locals.

contacts of the selector have separated. To silence the bell and reset the annunciator it is necessary only to depress the key momentarily, thus breaking the circuit to ground. This causes the 100-ohm magnet to release its armature, so that when the key is released, the bell circuit will remain open until the selector local contacts are again closed in response to the operation of the selector.

Figure 329 shows the connections necessary where the selector is connected into a single Morse line; the operation of the selector controlling a bell annunciator.

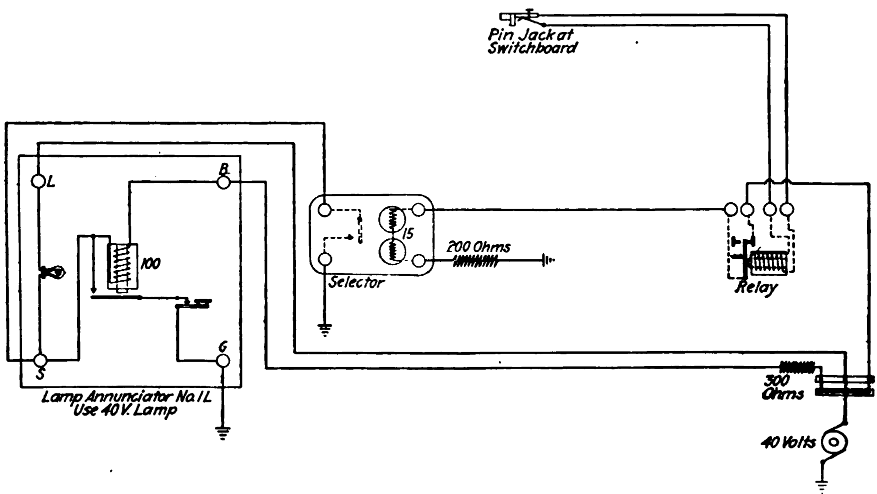


FIG. 333.—Selector connected to single-line repeater. 40-volt local battery.

Figure 330 shows the connections of a selector, annunciator, and bell combination at a way office, or on a single wire where gravity battery locals are used.

Figure 331 is the same as the arrangement shown in Fig. 328 except that the selector operates a bell annunciator instead of a lamp annunciator.

Figure 332 shows the connections required where the selector, annunciator, and bell equipment is used in connection with a single-line repeater at a repeater station, the annunciator and bell being operated by an extra battery consisting of two gravity cells.

Figure 333 shows the repeater-station connections where 40-volt battery is available for the operation of local circuits.

CHAPTER XVIII

HALF-SET REPEATERS. COMBINATION FULL-SET AND HALF-SET REPEATERS. "HOUSE" REPEATER CIRCUITS. DUPLEX AND QUADRUPLEX REPEATERS. DIRECT-POINT REPEATERS. LEASED WIRE INTERMEDIATE "DROPS"

A "half-set" repeater, consisting of one repeater transmitter and one repeater relay, is used where it is desired to connect a duplexed line or one side of a quadruplexed line with a single line. When such connection is made the duplexed portion of the circuit is used for transmission in one direction at a time only. The capacity of the entire circuit, therefore, is simply that of a single Morse circuit.

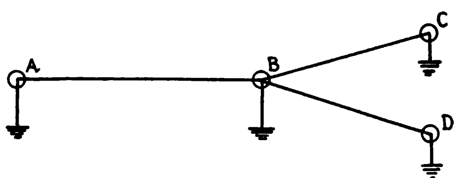


FIG. 334.—Two single lines connected to a quadruplexed line.

A wire may be quadruplexed between stations *A* and *B*, Fig. 334, and by employing two separate half-set repeaters, two branch lines operated as single Morse circuits between *B* and *C* and between *B* and *D* may be connected with the quadruplexed wire so that *A* will have direct communication with *C*, on, say, the polar side of the quadruplex, and with *D* on the neutral side of the quadruplex, and while transmission can take place in one direction only, at a time, over each half of the quadruplex, the arrangement provides that one wire between stations *A* and *B* will serve the purpose of two wires.

Figure 335 shows the main-line and local connections at a "Postal" terminal office where a single wire is connected into the polar side of a quadruplex, or a polar duplex. Line No. 1 entering the office is connected with the shoe of a spring-jack at the main-line switchboard, thence through one conductor of a double cord to the relay of a Weiny half-set repeater, returning via the tongue of the repeater transmitter, the other conductor of the double cord, the shank of the spring-jack, thence via the vertical brass strap of the switchboard, metal plug, and disk to battery and ground. Wire No. 4 connected with the shoe of its spring-jack is connected with the duplex set by means of a single conductor cord—the metal face of the wedge being in contact with the shoe and the insulating face with the shank of the spring-jack. The single wire extending from the pin-jack to the duplex set

makes the usual connections through polar relay, artificial line, pole-changer and battery. The local circuit extensions from the polar relay and the pole-changer to separate spring-jacks in the leg-board provide by means of a double conductor cord—connecting the polar relay spring-jack with the repeater sending side pin-jack—that the operation of the repeater transmitter will depend upon the opening and closing of the armature of the polar relay, and by means of a double conductor cord—connecting the pole-changer spring-jack with the repeater receiving side pin-jack—that the operation of the pole-changer will depend upon the opening and closing of the armature of the repeater relay. The operation of the combined sets may readily be

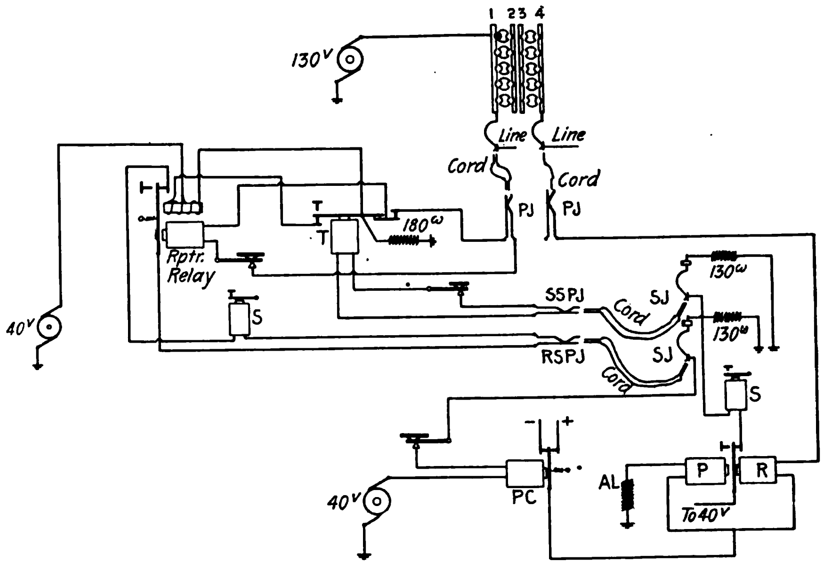


FIG. 335.—Single line connected to a duplexed line through a half repeater.

traced, and it will be found that when the key at the office on the single line is closed, the armature of the repeater relay will be in the closed position, also the armature of the pole-changer of the duplex will be in the closed position which provides that the receiving sounder circuit of the polar relay at the distant station on the duplexed line will be closed. When, on the other hand the single-line key is open, the armature of the repeater relay will be in the open position, the armature of the pole-changer of the duplex in the open position, and the receiving sounder circuit of the duplex at the distant station will be open. Thus the operation of the polar relay at the distant station is controlled by the operation of the transmitting key at the office on the single line.

The operation of the relay at the station on the single line is controlled by the operation of the pole-changer of the duplex at the distant station on

the duplexed line, by the reverse process, that is, when the distant pole-changer is closed the armature of the polar relay at the repeater station will be in the closed position, which in turn closes the repeater transmitter thereby applying battery to the single line, causing the single line relay to attract its armature. When the pole-changer of the duplex at the distant station is "open," the armature of the polar relay at the repeater station will be in the open position, thereby breaking the local 40-volt battery connection through the windings of the repeater transmitter, causing the latter to release its armature removing the main-line 130-volt battery from contact with the single line. Thus the operation of the single line relay is controlled by the operation of the pole-changer of the duplex at the distant station.

When two lines are connected in this manner, it is necessary that the pole-changer key of the duplex be kept closed while the station on the single line is sending, otherwise there will be no main-line battery applied to the single line at the repeater station.

When signals are being repeated from the duplexed into the single line, the repeater relay remains closed due to the action of the differential magnet mounted above the main-line magnet, as was explained in connection with Figs. 189 and 190.

Figure 336 shows the method of connecting up a Weiny-Phillips half-set repeater to a duplex or one side of a quadruplex, where gravity battery locals are used. Where such sets are installed in small offices, in some cases the half-repeater set is mounted upon an operating table so that it may be used as an operating set at the repeater office when desired. Additional local battery is placed in the local circuits of the half-repeater to insure "solid" signaling. The connections between the Morse and multiplex sets are made at the loopswitch by means of wedges and plugs as shown in the diagram.

Figure 337 shows the circuits of a Weiny half-repeater where 40-volt local current is used, employing the new type of repeater instruments used in the service of the Postal Telegraph-Cable Company. In those instances where 110-volt local battery is used in place of the regulation 40 volts, a 600-ohm resistance unit is placed in series with the 20-ohm holding coil of the relay. Also, the transmitters and sounders are wound to a resistance of 150 ohms and have 1,500-ohm resistance units in each of these circuits; the resistance units being placed next to the fuse block instead of next to the ground connection as shown when 40-volt battery is used.

Figure 338 shows the circuits of a Weiny-Phillips repeater arranged for use either as a full set or as a half set. Throwing the switches to the right provdies for the employment of the apparatus as a single-line repeater, *i.e.*, for repeating from one single line into another, while throwing the switches to the left converts the set into two separate half-repeaters. Also, with this arrangement when 110-volt local battery is employed, 600-ohm and 1,500-ohm resistance coils are used as explained in connection with Fig. 337.

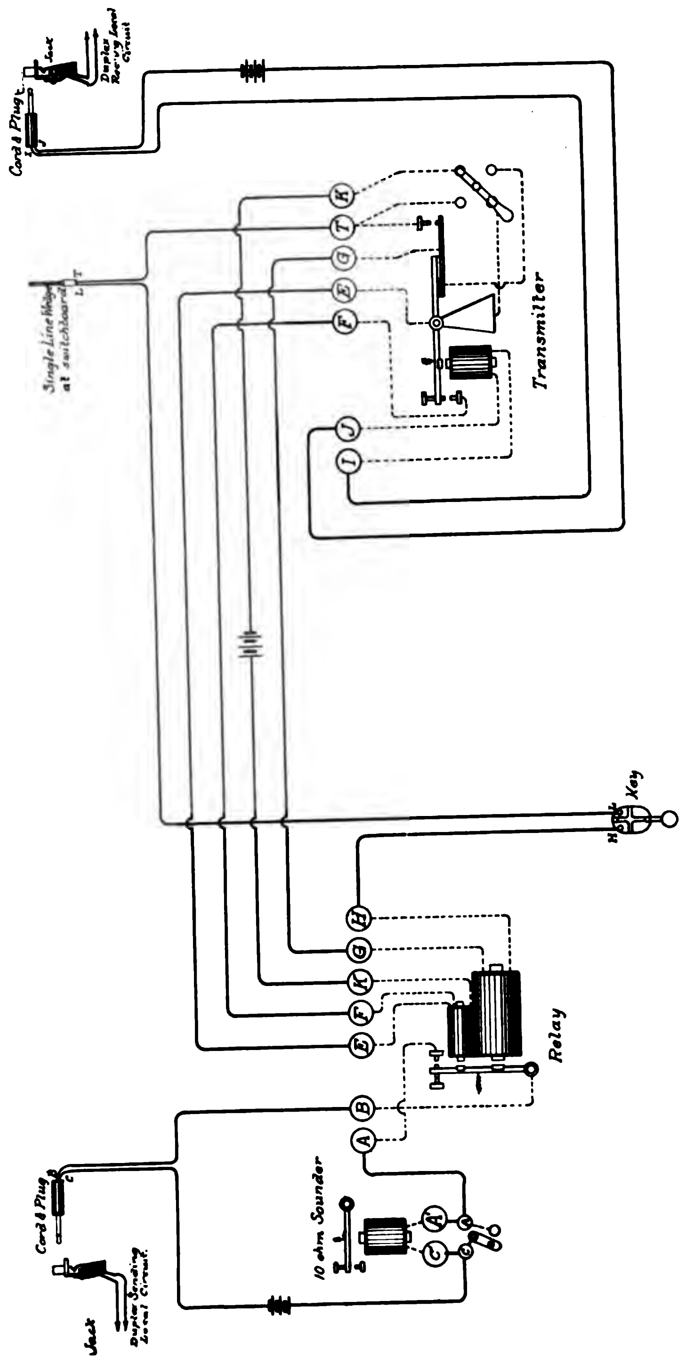


FIG. 336.—Weiny-Phillips half repeater using gravity battery to operate the transmitter.

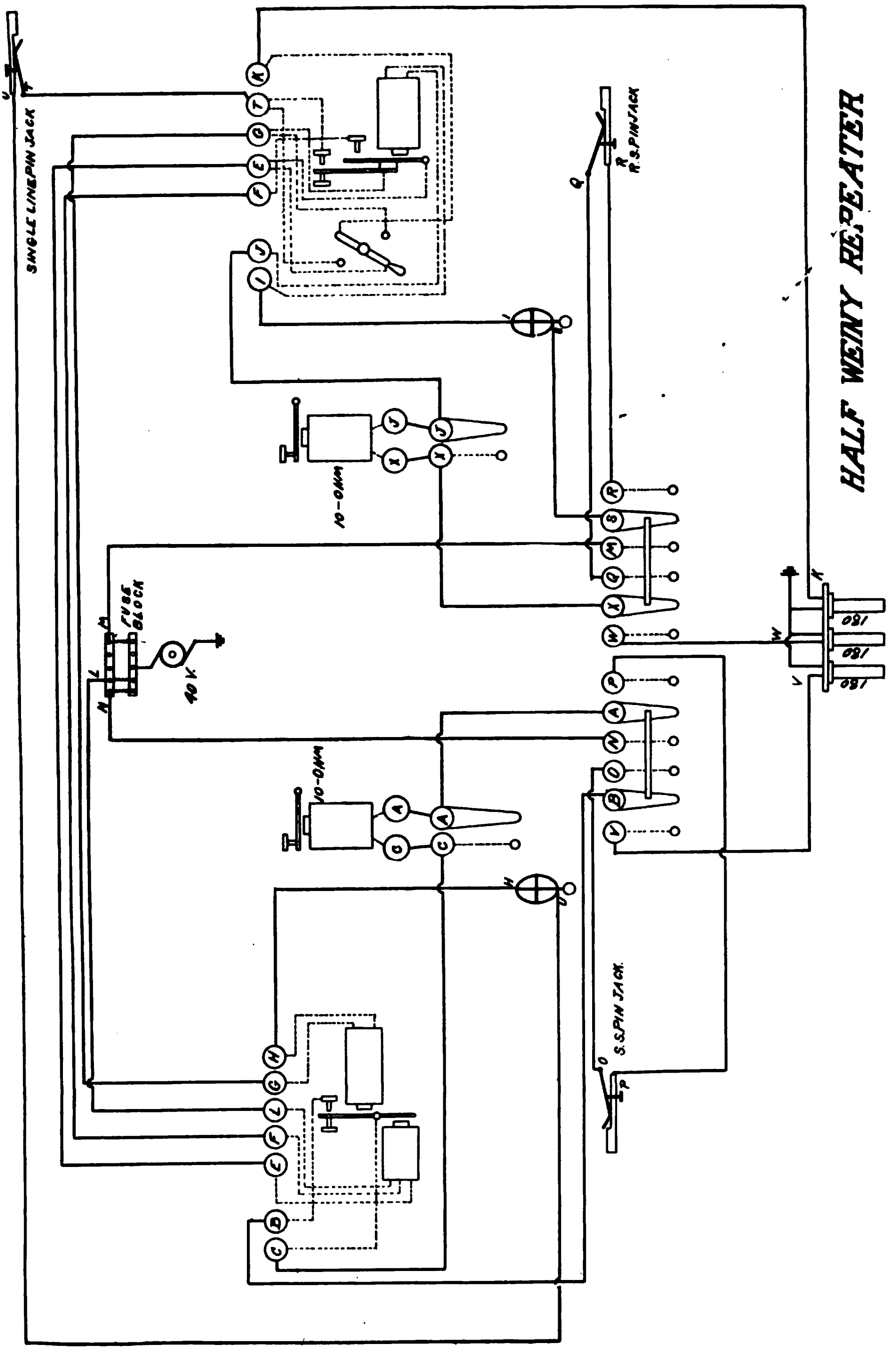


FIG. 337.—Half repeater arranged for dynamo operation of transmitter and sounders

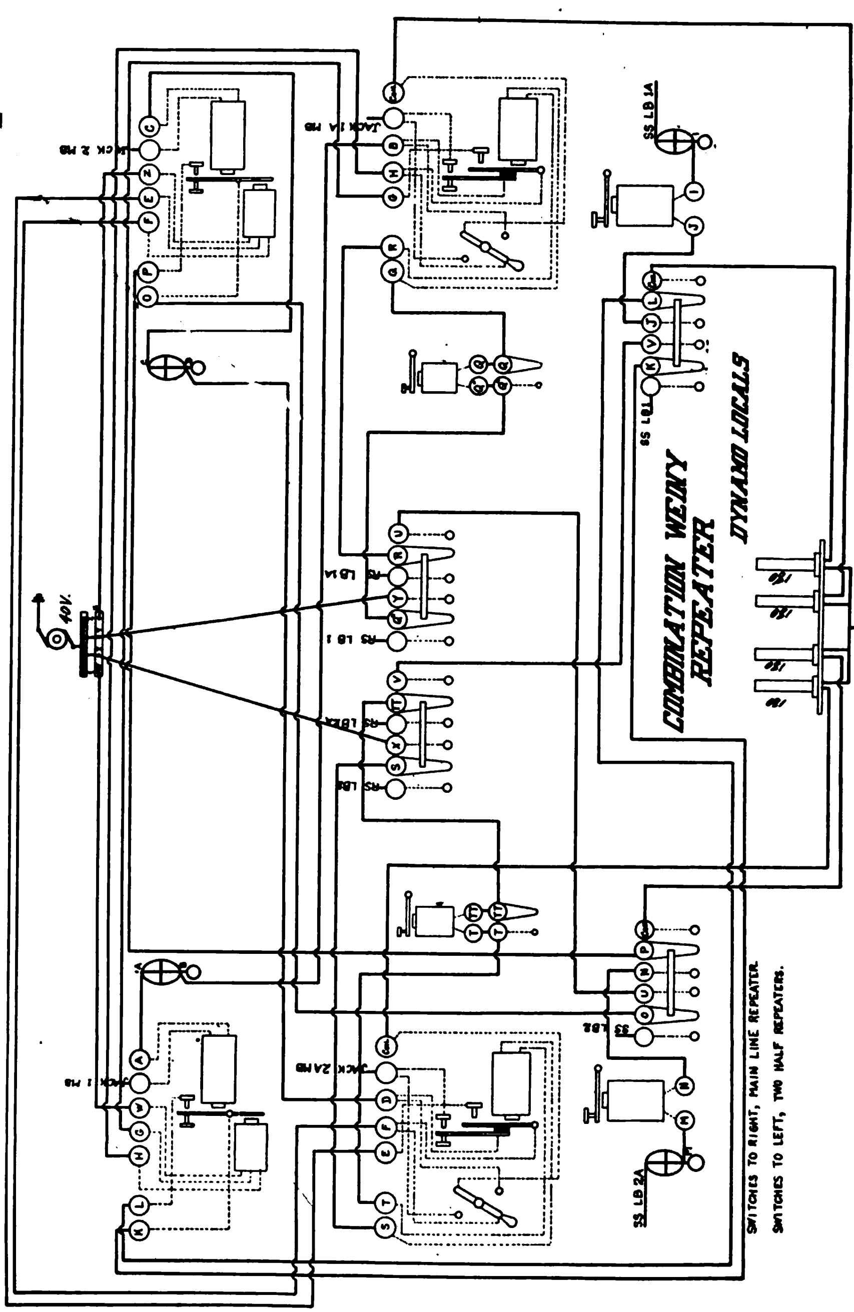

40V.
SWITCHES TO RIGHT, MAIN LINE REPEATER.
SWITCHES TO LEFT, TWO HALF REPEATERS.
DYNAMO LOCALS

Fig. 338.

Figure 339 shows the theoretical connections of a half-set Milliken repeater, from which it will be seen that the principle of operation is the same as that of the Weiny half set, and it might here be stated that any of the types of repeater described in the chapter dealing with single-line repeaters may be employed as half repeaters simply by using one-half of the apparatus required for a full set.

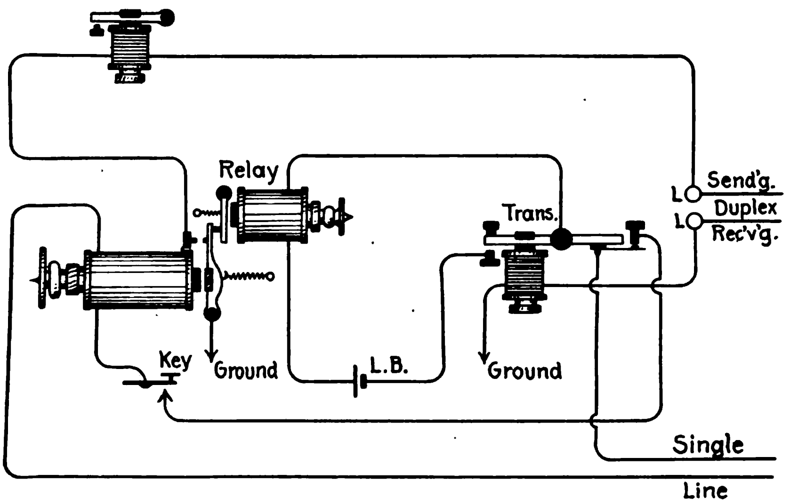


FIG. 339.—Milliken half repeater. Theory.

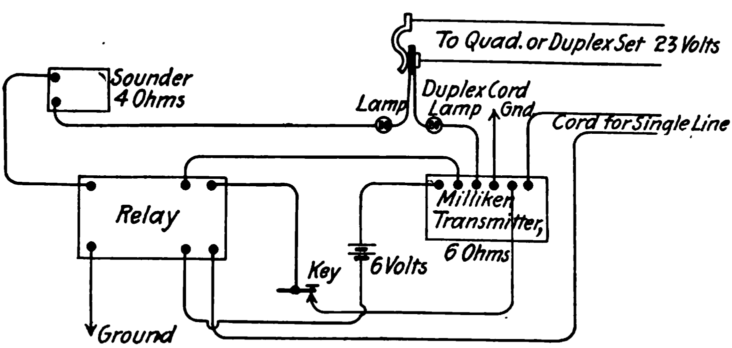


FIG. 340.—Instrument binding-post connections of the Milliken half repeater.

Figure 340 shows the actual binding-post connections of a Milliken half-repeater, the switchboard extensions being those used in the service of the Western Union Company.

Figure 341 shows the circuit arrangements of a house, or office repeater, which by means of a "double-flip" connection at the main switchboard

provides for the extension of the circuit to a branch office at the repeater station in such manner that the operation of the relay at the branch office

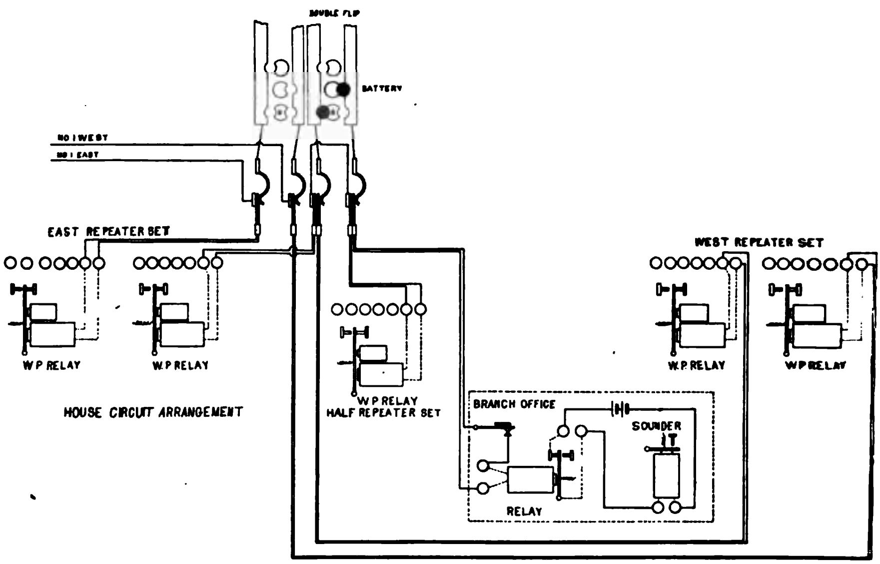


FIG. 341.—House-circuit repeater.

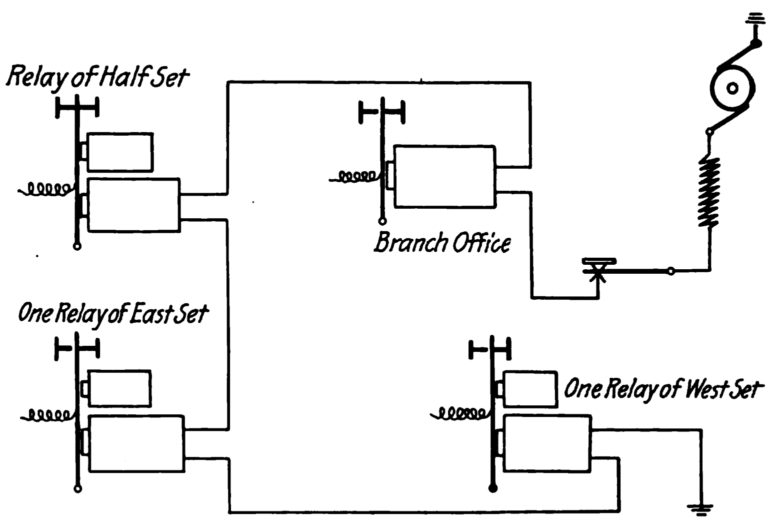


FIG. 342.—Theory of the house-circuit repeater.

will be more reliable and regular than when the branch office is simply looped in on the main line on one side of the single repeater. Fig. 342 shows

a theoretical diagram of the circuits as they stand when the switchboard connections have been properly made, and from which the operation of the combined sets may easily be traced. This arrangement is in use on the lines of the Postal Telegraph-Cable Company.

DUPLEX AND QUADRUPLEX REPEATERS

Notwithstanding the apparent complexity of multiplex telegraph apparatus, the arrangement of such apparatus for the purpose of repeating signals from one duplexed or quadruplexed circuit to another line similarly operated, is a comparatively simple matter. All that is required is that the electromagnet which actuates the transmitter or pole-changer of a particular circuit be included in the same local circuit with the contact points of the receiving relay connected into another line. By means of loopswitch, or leg-board connections the opening and closing of the armature of the neutral relay or the polar relay of one quadruplex set may be made to operate the transmitter or the pole-changer of another quadruplex set. When signals are automatically passed through repeater stations by interconnecting the local circuits of separate quadruplex sets, the arrangement of circuits is termed a simple quadruplex repeater.

DIRECT-POINT DUPLEX REPEATERS

With a view to eliminating one pair of points through which the signals must pass in being repeated from one line to another, the direct-point, or direct-repeating polar duplex has been introduced in the service both of the Postal Telegraph-Cable Company, and the Western Union Telegraph Company. With this arrangement the respective armature levers of two polar relays at the repeater office connect the positive and negative main battery potentials directly to the line wires. The principle upon which the system operates will be understood by referring to the theoretical diagram, Fig. 343. Assume, for instance, that the distant eastern office has closed the key. The armature of the polar relay at the repeater station will be attracted into the position shown in the diagram—the closed position. This results in placing the duplex negative battery in contact with the line west. As the current passes differentially through the coils of the polar relay, the armature

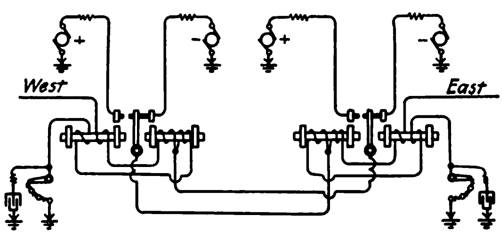


FIG. 343.—"Postal" direct-point duplex repeater. Theory.

lever of the west relay will not be affected by the out-going impulse. At the instant the key at the distant eastern office is opened, the opposite battery pole is presented to the line, which results in the armature lever of the relay at the repeater station moving into contact with the positive battery terminal, causing a reversal of current in the line west. It will be noted that each line is grounded at the repeater station in the same manner that any duplexed line is grounded.

Figure 344 shows the connections of the direct point repeater used by the "Postal" company. The arrangement illustrated is that employed where the connections between separate duplex sets are made at the leg-board. The

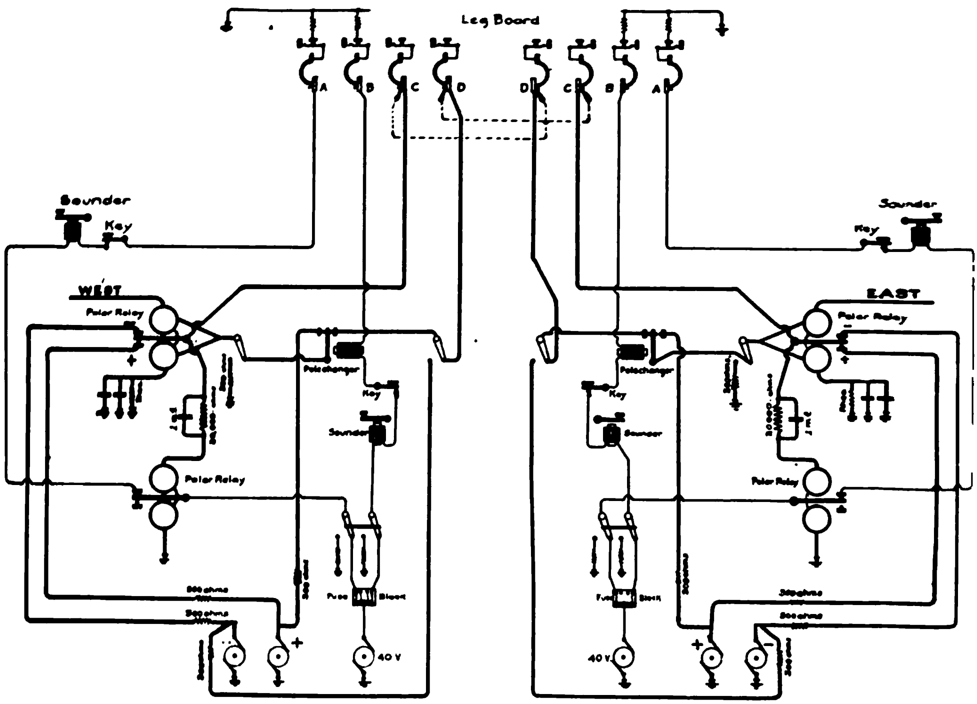


FIG. 344.—Instrument, table switch, and leg board connections of the Postal direct-point repeater.

eastern wire, connected through the main-line side of the polar relay, is brought to the switch which is the dividing point between the main and artificial lines. From there the circuit extends by way of the leg-board, to the armature tongue of the west polar relay, which, in making connection with its open and closed contact points introduces either a positive or negative current for the operation of the eastern circuit, so that, when the western relay is being operated due to main-line battery reversals at the distant western station, it causes reversals of main-line current to be directly commu-

nicated through its armature lever to the eastern circuit, which, being duplexed, the eastern polar relay at the repeater station is uninfluenced thereby, and likewise the operation of the western line is directly dependent upon the movements of the tongue of the east polar relay at the repeater station.

When the lever of the ground switch is moved into connection with the 300-ohm "ground" coil, the circuit is grounded through a resistance which equals that of the dynamos and the internal resistance coils. This switch is used in the operation of balancing.

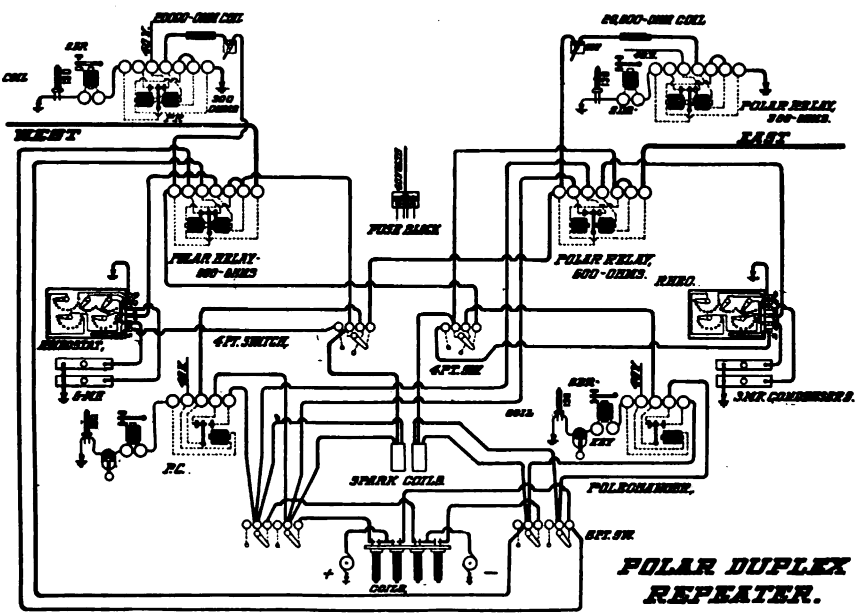


FIG. 345.—Binding-post connections.

Connected to the tongues of the east and west relays at the repeater station, are auxiliary artificial circuits extending through 20,000-ohm coils to extra polar relays (the coils of which are connected for series operation) which are used to operate reading sounders at the repeater station. It is evident that as the local contact points of the main-line relays are, in this system, used to make main-line battery applications, the points are not available for the operation of reading sounders as is the case with the ordinary duplex. The 20,000-ohm circuit is referred to as the "leak" relay circuit, and although the strength of the current traversing the windings of the leak relay is quite small, it is found that when the relay is properly adjusted the current reversals taking place in the main line, result in clearly reproduced signals in the sounder operated by the leak relay.

Figure 345 shows the actual binding-post connections of a "Postal"

direct-point repeater set, the two duplex sets being wired together so that it is not necessary to interconnect the sets at the leg-board. In the same manner it is possible to connect the polar sides of two quadruplex sets together in order that they may be used as a direct repeater.

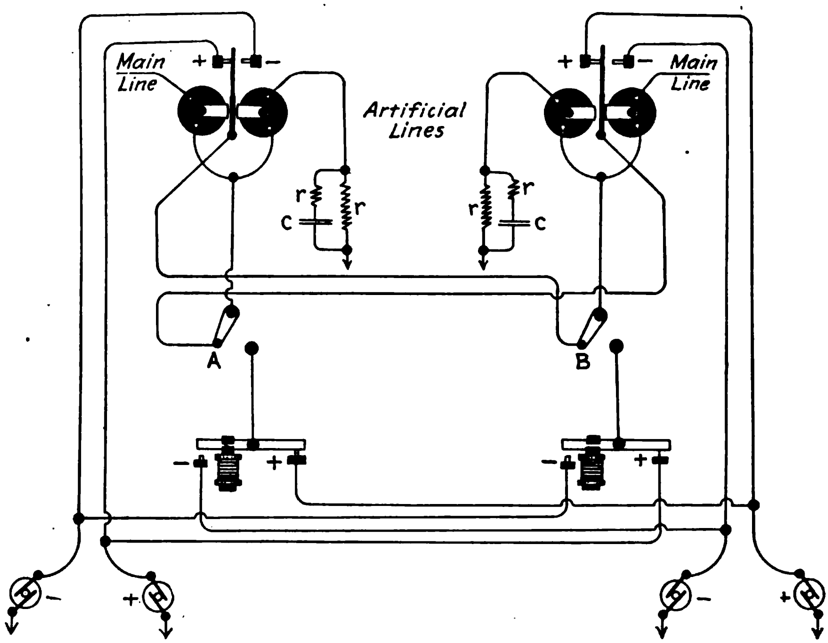


FIG. 346.—Barclay direct-point duplex repeater.

Figure 346 shows a diagram of the wiring of the direct-point repeater used in the service of the Western Union Company, from which it will be seen that the principle of operation is identical with that of the Postal's direct repeater. In fact, the only difference in the two systems is in the method availed of to provide a reading sounder circuit. For this purpose the Postal Company employs a leak relay, while the Western Union Company employs the Barclay polar relay which is equipped with a double-lever armature. The armature of the main-line relay has fixed to it two contact levers, one controlling the application of the duplex potentials, while the other; moving in unison therewith, closes and opens a local sounder circuit in the same way that the lever of an ordinary polar relay operates its reading sounder circuit.

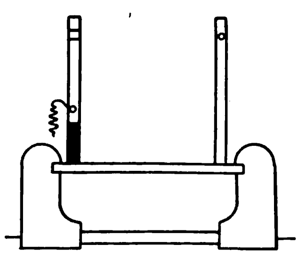


FIG. 347.

Figure 347 shows a view of the double-lever armature employed for the purpose; the levers, of course, are insulated from each other.

BRANCH OFFICE CONTROL OF DIRECT POINT REPEATERS

Figure 348 is a diagram of the circuits of a direct-point repeater showing branch-office control at the repeater station.

The local connections shown are those of the Postal Telegraph Company's repeater, but the method is applicable, as well, where the Barclay relay is employed.

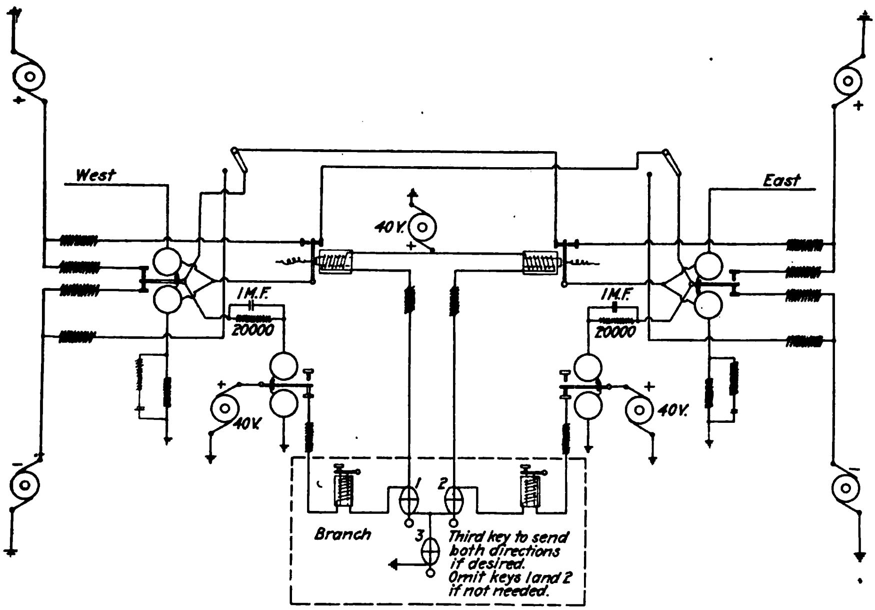


FIG. 348.—Branch office control of direct-point repeater.

It will be observed that the center key at the branch office, when closed, completes a ground connection, thereby combining the four wires extending to the branch office into two grounded loops, each loop including the polar relay and pole-changer local circuits of one of the duplex sets forming the repeater. Key No. 1 at the branch office is used when that office desires to communicate with the distant western office only. Key No. 2 is used when the branch office desires to communicate with the distant eastern office only, and key No. 3 is used when the branch office wishes to transmit to the west and to the east at the same time. How this is accomplished is apparent when it is noted that at the instant key No. 3 is opened, the ground contact is removed from the loops, and if the local circuits are traced in both directions from the 40-volt dynamos, it will be seen that the action of one dynamo

is opposed by that of the others, as a consequence of which the magnets of the two sounders and two pole-changers are de-energized, permitting the armature lever of each instrument to move into contact with its back-stop due to the action of its actuating spring. When the No. 3 key is closed in the act of signaling, the ground connection is reestablished causing the four armatures to respond and make contact with their front-stops.

A similar branch-office arrangement is sometimes employed where simple quadruplex repeaters are used. Fig. 349 shows the theoretical connections at the main and at the branch office where this method is used in connection with ordinary quadruplex repeaters. In order that the main office may transmit in both directions when called to the circuit, an extra key controlling the operation of an extra pole-changer in each duplex set is connected as shown in the diagram.

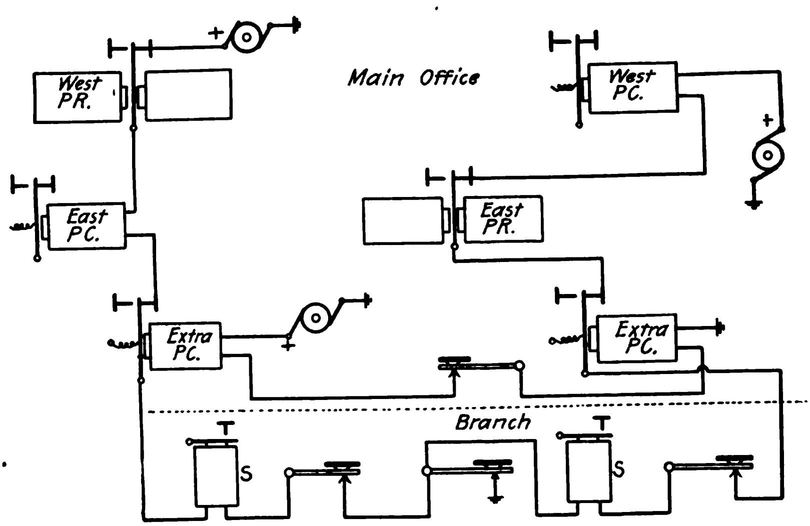


FIG. 349.—Branch office control of simple quadruplex repeaters.

Instead of using two extra pole-changers at the main office to enable the attendants there to operate the circuit, the ground connection may be extended from the branch-office grounding key, back to the main office as indicated in Fig. 350.

The switching connections necessary at the main office to apply this method of branch-office control to quadruplex or duplex systems wired in the usual manner, are made by means of cords and wedges at the leg-board.

Figure 351 shows the required leg-board connections, where the Postal Telegraph-Cable Company's leg-board system is employed. The sending and receiving local circuits of a duplex set, or of the polar side of a quadruplex set are shown in the upper portion of the diagram, while the sending

and receiving local circuits shown in the center portion of the diagram are those of the duplex, or polar side of the quadruplex connected therewith for the purpose of repeating from one line to another.

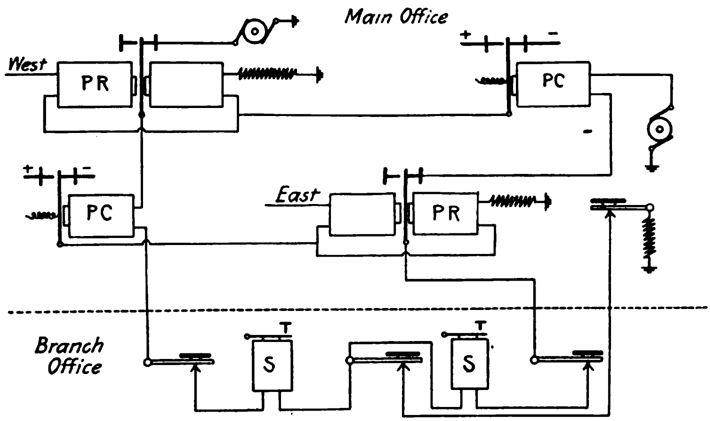


FIG. 350.—Center key ground connection extended to main office.

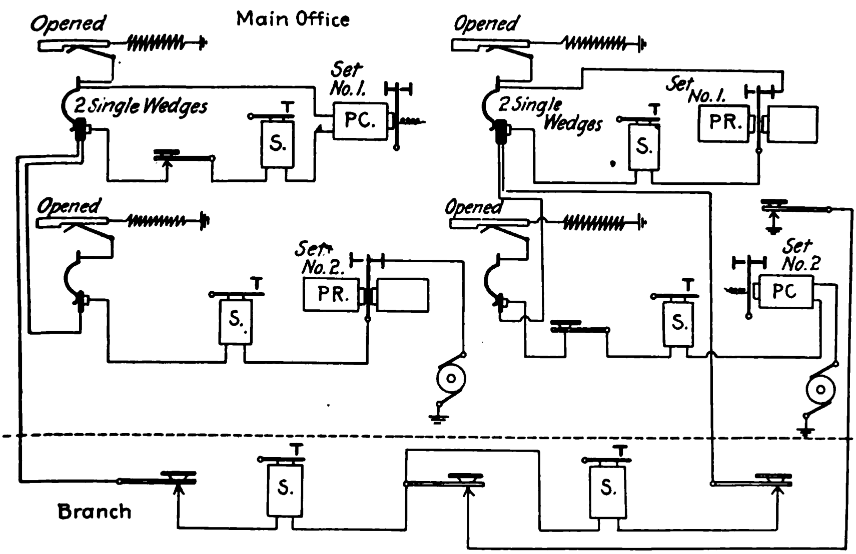


FIG. 351.—Leg board cord connections providing branch office control of duplex repeater.

In addition to the flexible cord connections made at the leg-board it is necessary that the 6-point "local" switches of set No. 1 be thrown "apart," and that the 6-point "local" switches of set No. 2 be thrown "together" (see Figs. 295 to 298 inclusive).

BRANCH OFFICE COMBINATION SETS

In the interest of flexibility it is advisable to provide a switching arrangement at the branch office by means of which the loop extending to the main office may be used for either single or duplex operation. Fig. 352 shows the connections necessary where a 6-point switch is used for this purpose. Moving the levers of both switches to the left provides for duplex service, while moving the switch levers to the extreme right provides for single-line operation.

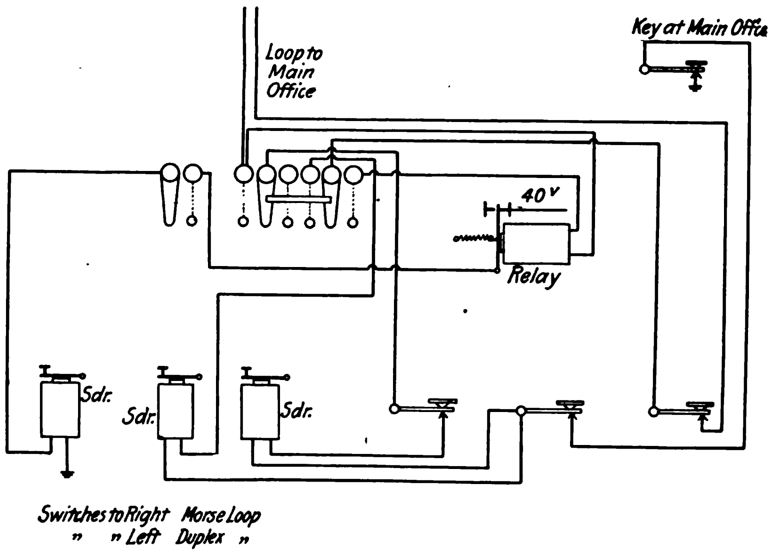


FIG. 352.—Branch office combination set where branch office controls the operation of pole-changer at main office.

DUPLEX CONNECTED WITH A BRANCH OFFICE OVER A SINGLE CONDUCTOR

For emergency service, where the number of conductors extending to a branch office, convention hall, or athletic field must be employed to the best advantage, and where it is not convenient to use half-repeaters, the arrangement depicted in Fig. 353 has been used with excellent results. The shaded portions of the wedges represent the metal faces in contact with the shoe and the shank, respectively, of the spring-jack, the same being separated electrically by the reverse, or insulating surface of each wedge.

When multiplex local circuits are extended to branch offices over single conductors as here shown, it is necessary to "split" the multiplex local battery switch so that the local battery will be removed from the receiving relay circuit. The pole-changer local circuit will then be connected as when the

local battery switch is thrown to the right, and the receiving relay will be connected as when the battery switch levers are thrown to the left (see Figs. 295 and 298).

With this arrangement the sender on the duplexed line gets his own writing in the receiving relay. It is necessary, therefore, that all keys in

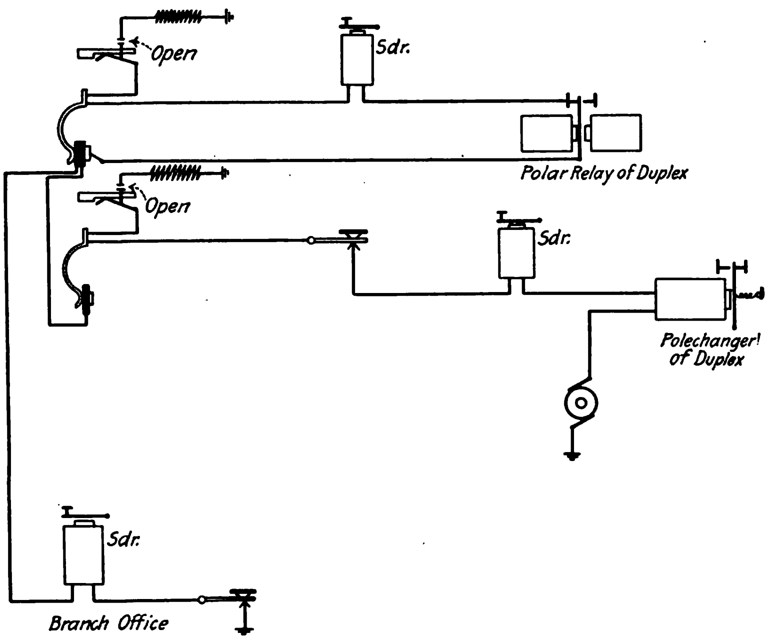


FIG. 353.—Branch office control of a duplex over a single conductor where half repeater not available.

circuit at the branch, main and distant offices be kept closed when not being used in the act of transmitting.

The act of interrupting, or "breaking" the sender is accomplished in the same manner as if the circuit were being operated as a single Morse wire, and although transmission may be carried on in one direction only at a time, the arrangement makes possible the employment of the highly efficient duplex between terminal offices.

THE O'DONOHUE "SHUNT" REPEATER

In the operation of the ordinary duplex or quadruplex repeater, the tongue of the polar relay is required to travel from its open to its closed contact point, before the battery circuit controlling the operation of the pole-changer of the companion set is closed, with the result that in the operation

of circuits in which the current strength is not up to standard, the duration of contact between the tongue and closed contact of the relay may be too brief to permit of firm and solid signaling. Fig. 354 shows the theoretical wiring of a repeater arrangement devised by J. P. O'Donohue, which has for its object the prolongation of the "marking" contact of the pole-changer lever.

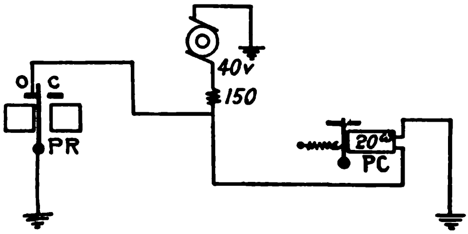


FIG. 354.—O'Donohue shunt repeater.

By referring to the diagram it will be seen that while the tongue of the relay is in contact with its back-stop, a short-circuit path to ground is presented to the local battery, which shunts the current from the electromagnet windings of the pole-changer, resulting in the release of its armature. When a marking current is impressed upon the line at the distant station the resulting movement of the relay tongue into the closed position occupies a portion of the time of the marking contact, which lessens, to an equal extent, the duration of the marking contact of the companion pole-changer tongue. The O'Donohue repeater introduces a time element which favors the marking contact, as, it is apparent from the diagram that at the instant the relay tongue departs from its back contact, the shunt path is removed, permitting current from the local battery to energize the pole-changer magnet without waiting until the relay tongue has completed connection with its front, or closed contact.

WORKING AN INTERMEDIATE MORSE LOOP IN A DUPLEXED CIRCUIT

In leased wire, and press service, it is sometimes advisable to avail of the advantages of duplex apparatus at terminal offices, and still maintain one or

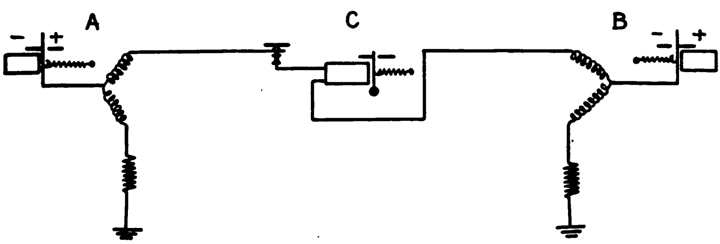


FIG. 355.—Operating an intermediate Morse loop in a duplexed circuit.

more intermediate offices between terminals where it is possible to employ only simple Morse equipment.

Figure 355 shows the conventional scheme of the polar duplex at two terminal stations *A* and *B*. If the duplex battery connections at both

stations are made so that opposite "poles" are to line when both pole-changer keys are closed, an intermediate office using a single-line relay, may be connected into the main-line circuit at a point any distance from either terminal as depicted in the sketch. So far as the intermediate office is concerned the circuit is operated in the same manner as a single line is operated:

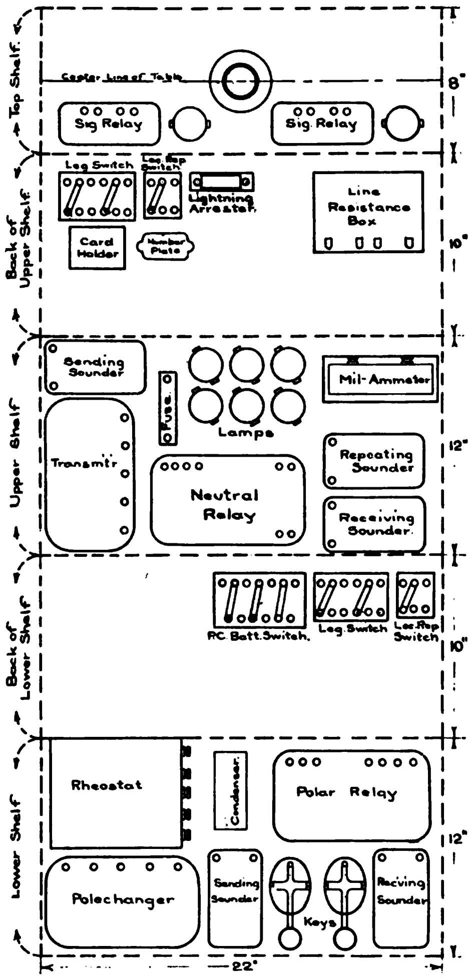


FIG. 356.—Arrangement of apparatus on repeater tables in Western Union service.

opening the key at the intermediate office opens the main-line circuit, which results in the tongues of the polar relays at the terminal stations being moved into the spacing position due to current traversing their compensation circuits only, and, as while both keys are closed at the terminal stations unlike battery poles are to line; closing the key at the intermediate office

results in a flow of current through the main-line coils of the polar relays at the terminal stations, sufficient in strength to move the relay tongues into the closed, or marking position, which current at the same time energizes the magnet of the intermediate Morse relay. Thus the operation of the key at station *C* results in the operation of the polar relays at both terminal stations.

When station *A* is sending it is necessary that station *B* keep the key closed, and *vice versa.* It is evident, for instance, that while the key at *B* remains closed, closing the key at *A* results in all relays being energized, and

FIG. 357.—Multiplex repeater instrument rack used in "Postal" offices.

that opening the key at *A*—thereby presenting like poles to line at each end of the circuit—results in cessation of current in the main line, with a consequent movement of all relay tongues into the open, or spacing, position.

Figure 356 shows the proper arrangement of apparatus on multiplex repeater tables, in the service of the Western Union Telegraph Company, while Fig. 357 shows a photograph of the type of sectional multiplex repeater shelving used by the Postal Telegraph-Cable Company in offices recently equipped. Each vertical tier of four shelves accommodates the complete equipment of two quadruplex sets, one quadruplex facing the aisle on each side of the rack.

CHAPTER XIX

THE PHANTOPLEX

Phantoplex apparatus used in association with ordinary Morse equipment, permits an additional superimposed transmission of Morse signals over a wire that is at the same time being operated as a single, duplexed, or quadruplexed circuit, without interference between the two methods of signaling.

The operation of the system will be understood by considering the arrangement of circuits as depicted in Fig. 358 which shows the terminal

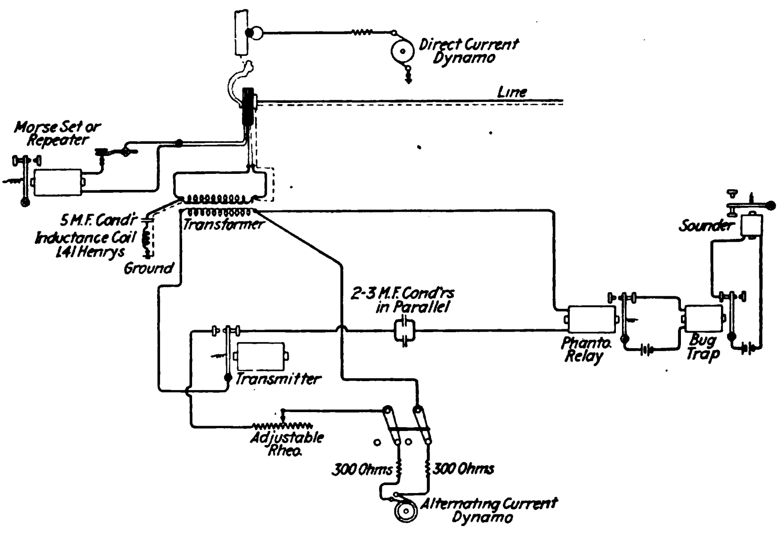


FIG. 358.—Theory of the phantoplex.

office switchboard and instrument wiring of a 60-cycle phantoplex superimposed upon a line which is also being operated as a single Morse circuit.

A combination system as here illustrated may be used for two transmissions in either direction at a time, or for one transmission in each direction at a time. The combination has an advantage over polar duplex systems; in that, double transmission may be carried on in one direction, whereas, with the latter, double transmission implies that one message at a time in each direction, only, can be transmitted.

The system is particularly useful where the bulk of the traffic handled between two offices moves in one direction.

Referring to the diagram: it will be seen that the ordinary Morse circuit extends from one brush of the direct-current dynamo to the battery disk of the main switchboard, thence via the vertical strap, shank of the spring-jack, and one side of the double wedge on the left, to the key and relay of the Morse set. Returning from there to the other side of the double wedge which is in metallic contact with one face of another double wedge having connected with its opposite conducting surfaces, the terminals of the secondary winding of a transformer.

It is evident in the diagram, that an uninterrupted circuit extends from the direct-current dynamo, via the Morse relay, and secondary of the transformer, to line and ground at the distant station.

When the system was first introduced, frequencies as high as 175 cycles were employed to operate the phantoplex relays, but it was found that the inductive disturbances created in adjacent conductors, especially in parallel telephone circuits, due to the rapid alternations in the telegraph wire, were so detrimental to the general service, that it was decided to use frequencies no higher than 125 cycles per second, even though the efficiency of the "phantom" circuit, was, as a result thereof considerably reduced.

Tracing the phantoplex wiring, it will be seen that one end of the primary coil of the transformer is connected to one brush of an alternating-current generator. The other end of the primary coil is connected to the tongue of an ordinary transmitter, which is operated in the usual manner by a Morse key and local battery (not shown). The other brush of the alternating-current generator is connceted to the back contact of the transmitter by way of an adjustable rheostat. A branch wire is connected with the first-mentioned terminal of the primary coil, forming a static circuit via the phantoplex relay, condensers, closed contact point of the transmitter, and tongue of the latter, to the opposite terminal of the primary coil of the transformer.

The phantoplex relay is equipped with a very light, and delicately poised armature to which a light tongue is attached. The tongue is normally held in contact with its back-stop by the action of a light retractile spring.

With the tongues of the transmitter, relay, bug-trap, and sounder in the positions shown in Fig. 358, it is evident that the phantoplex transmitting keys at the home station and at the distant station are closed, for, when the operator at, say the distant station, closes his key he causes the tongue of his transmitter to open the primary circuit of the transformer at that station, thereby interrupting the flow of alternating current in the line wire, and, as the main-line circuit includes the upper winding of the transformer at the home station, there will be no induced e.m.f. in the lower winding of the transformer at the latter station, as a consequence of which the tongue

of the home phantoplex relay will make contact with its open point, thereby closing the bug-trap relay circuit, which in turn closes the reading sounder circuit. When, on the other hand, the distant office opens his key, the action results in the tongue of the distant transmitter closing the alternating-current generator circuit through the primary coil of the transformer at that station, causing a high frequency alternating current to be induced in the upper winding of the transformer, and, as the upper winding is included in the main-line circuit, the alternating current is transmitted over the line, energizing the upper winding of the home transformer which induces a similar current in the lower winding, causing the phantoplex relay connected therewith to attract its armature, thereby opening the bug-trap and reading sounder circuits.

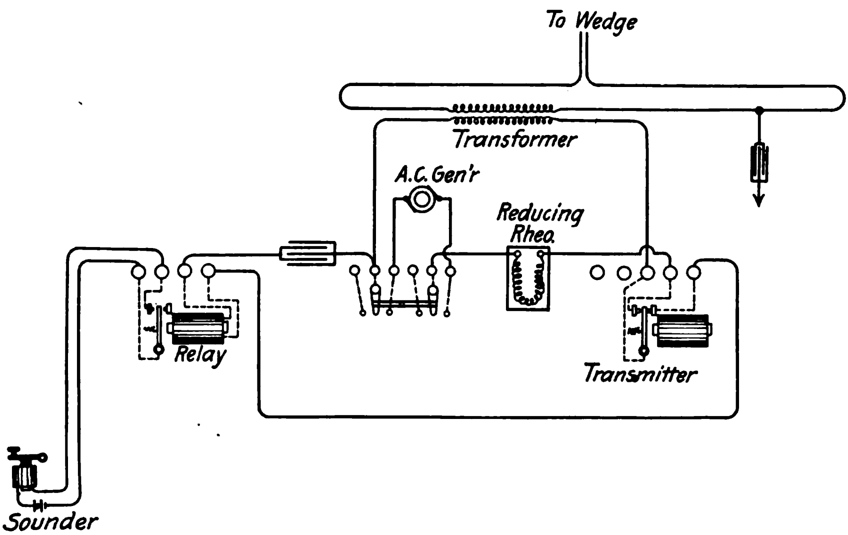


FIG. 359.—Phantoplex without bug-trap relay.

The operation of the phantoplex is easily memorized if it is remembered that the high frequency current is impressed upon the line when the transmitter key is open, not when the key is closed, and that the reading sounder is closed when the phantoplex relay is "open."

When a single Morse circuit has a phantoplex circuit superimposed upon it, the Morse relays do not respond to the dots and dashes formed by the alternating-current impulses, owing to the fact that when the Morse keys are closed, the direct current from the Morse battery is of sufficient strength to hold the relay tongues in the closed position and when any Morse key in the circuit is open, the retractile springs attached to the levers of the Morse relays are strong enough to hold the levers against their back-stops. Careful adjustment of the Morse relays is necessary, but if the

direct-current strength is not less than 75 milliamperes, and the retractile springs are adjusted to have a strong "pull," under ordinary circumstances the Morse relays will be unaffected by the high frequency currents passing over the line.

In case there are intermediate Morse stations in circuit between the terminal stations where the phantoplex sets are installed, it is necessary to bridge each intermediate office with a condenser, so that when the Morse key at any office is opened, the phantoplex currents will have an uninterrupted path.

Figure 359 shows the binding-post connections of a phantoplex set as installed at a terminal office where leg-board facilities are available. In the arrangement here shown, the set is wired so that the phantoplex relay local contact points control directly the operation of the reading sounder, without the intermediary of a bug-trap relay.

THE POLAR PHANTO-QUADRUPLEX

The phantoplex can be superimposed upon a wire that is already being operated by the differential polar duplex or quadruplex systems as shown

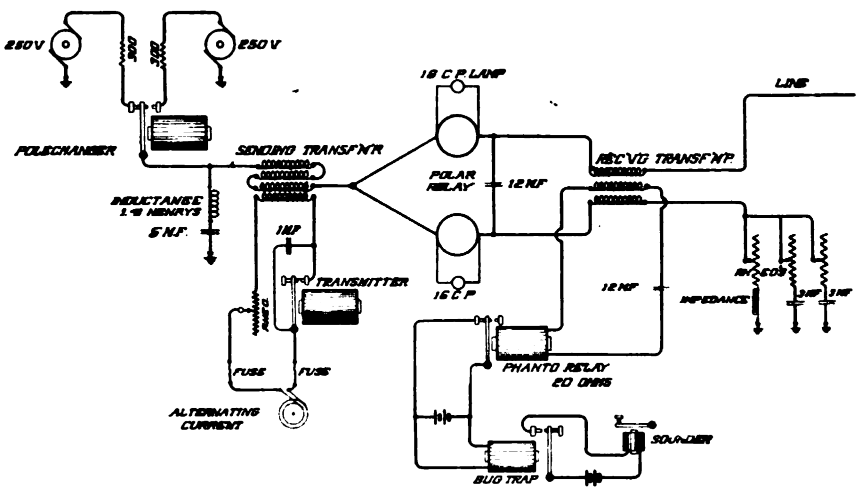


FIG. 360.—Phantoplex duplex superimposed upon a polar duplex circuit.

in Fig. 360. All that is necessary is to provide a static path for the alternating currents between the secondary coil of the transformer and the earth at the stations where the transformers are inserted in the main-line circuit, care being taken to connect the condenser to the terminal of the secondary winding nearest the earth contact, and on the opposite side of the transformer to which the main-line wire leading to the distant station is connected. For the best results, too, it is necessary that the artificial lines at both ends

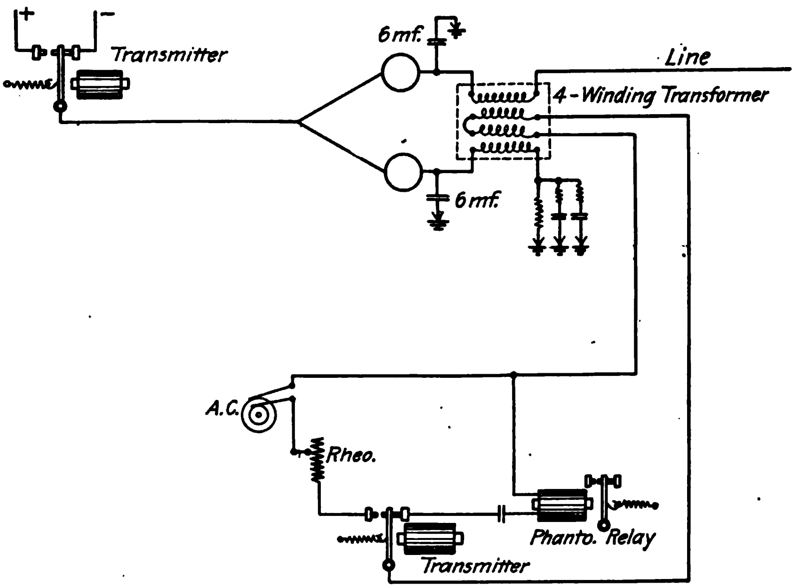


FIG. 361.—Single phantoplex superimposed upon a polar duplex circuit.

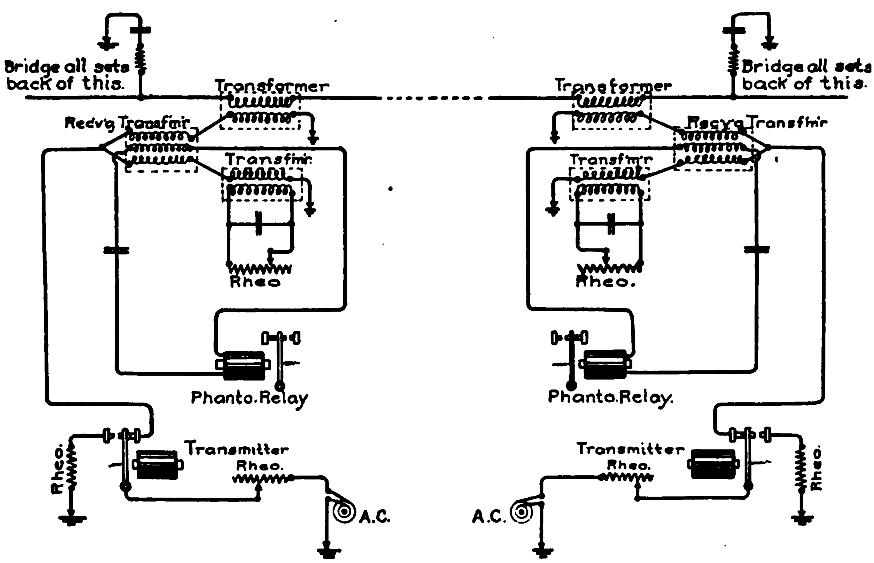


FIG. 362.—Phantoplex duplex superimposed upon a single Morse circuit.

of the circuit be so built up that they will, as nearly as possible, imitate the resistance, capacity, and inductance of the real line.

The phanto quad system illustrated in Fig. 360 consists of a phantoplex-duplex and an ordinary polar duplex. The phantoplex half of the system takes the place of the Stearns' duplex half of the ordinary differential quadruplex. The sending transformer has three coils of a four-coil transformer connected in series, forming the secondary winding. The outgoing signals from the pole-changer of the polar side pass through the secondary winding of the sending transformer, thence differentially through the polar relay and the two outside windings of the receiving transformer, without affecting the home phantoplex relay.

An incoming signal from the distant pole-changer passes through the primary winding of the receiving transformer without inducing a current in the secondary winding of sufficient strength to operate the phantoplex

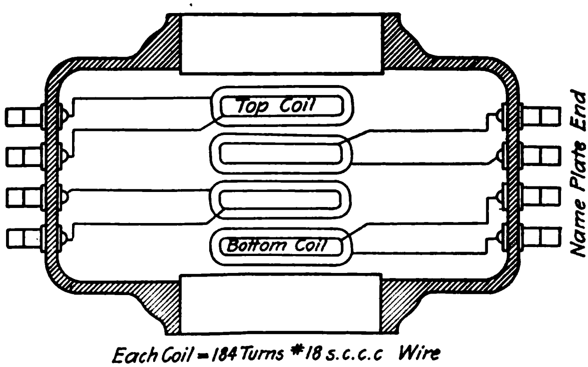


FIG. 363.—Circuits of the receiving transformer.

relay. When, however, the high frequency current from the distant alternating-current generator passes through the primary of the home receiving transformer, a current is induced in the secondary winding of the required strength to operate the phantoplex relay.

Careful consideration of the action taking place in the various transformers when phantoplex currents are impressed upon the line at each end will show that the intended signal is made by the home alternating-current generator in practically the same manner as the intended signal, in the case of the polar duplex, is made by the home battery through the compensation circuit, when like poles are to line at both ends of the circuit.

Figure 361 shows the terminal connections of a single phantoplex circuit superimposed upon a polar duplex circuit. It is found in practice that the 6-m.f. condensers shown tapped off either side of the polar relay may with equally good results be replaced by a shunt circuit around each side of the polar relay, consisting, in each case, of a 16-c.p., 220-volt carbon incandescent

lamp, furnishing a non-inductive path for the high frequency currents outside of the relay coils.

Figure 362 shows the instrument and transformer connections of a phantoplex-duplex superimposed upon a single Morse line.

THE PHANTOPLEX TRANSFORMER

The transformer used in the one way single phantoplex (Fig. 358) has a winding ratio of 1–1. That is, the primary winding and the secondary

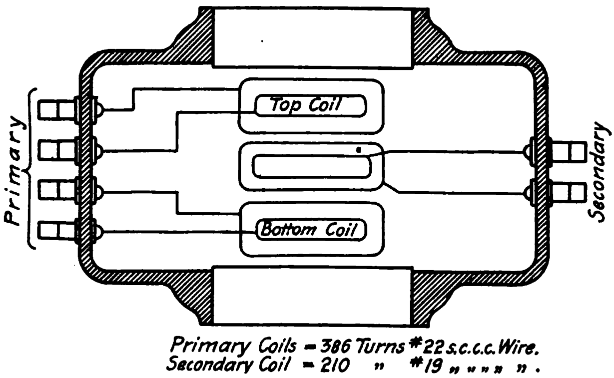


FIG. 364.—Circuits of the sending transformer.

winding have an equal number of turns of wire of the same size, namely, 425 turns of No. 19 B & S., gage, single silk-covered wire in each winding.

Figure 363 shows a drawing of the receiving transformer, indicating the relative positions of the primary and secondary coils. The resistance of the primary winding is about 9 ohms.

Figure 364 gives a similar view of the sending transformer.

CHAPTER XX

HIGH-SPEED AUTOMATIC TELEGRAPHY

THE WHEATSTONE AUTOMATIC

Of the many systems of automatic telegraphy invented and tried out in actual service since the Morse telegraph was introduced about 75 years ago, the system which has been most extensively employed and which has been found to answer the requirements of service most satisfactorily is that known as the Wheatstone Automatic.

In the Wheatstone system of automatic telegraphy, the dot and dash combinations which form the letters of the alphabet are perforated in the Morse code on specially prepared strips of paper about 1/2 in. in width. When the letters and words forming the message or messages have been perforated in the paper strip the latter is then passed through a Wheatstone transmitter which is connected into the main-line circuit, and driven by an electric motor.

The Wheatstone transmitter is practically a high-speed pole-changer operated automatically instead of by means of a Morse key in the hands of a telegrapher, as is the case with manually operated single and multiplex telegraphs.

The preparation of the transmitting tape is accomplished by means of three-key mallet perforators, or by keyboard perforators, which may be operated by any telegrapher after a little practice.

If the Wheatstone transmitter is run at slow speed the transmitted Morse signals can be read by sound in the receiving relay (or from a sounder connected thereto) in the same way as hand sending may be read, as the Morse is plain and accurate. When the motor which drives the transmitter is speeded up, the rate at which signals can be sent over the line may reach 300 or 400 words per minute, depending upon the speed of the repeaters in circuit—if any are employed,—upon the *KR* limitations of the line wire, and upon the speed at which the polar relay at the receiving end of the line will work satisfactorily.

It is the usual practice to operate the system duplex, which means that most of the apparatus of the ordinary polar duplex is retained. At the receiving end the armature of the polarized relay has attached to it an extension arm bearing an inking wheel, which, when the tongue of the relay is in the spacing position (against its back-stop), is held close to, but not touching, a moving band of paper tape, and which, when the tongue

of the relay is moved into the marking position, makes contact with the moving paper slip, causing an ink mark to be made thereon of a length depending upon the time the relay tongue is held in the marking position. As the speed at which the tape travels under the inking wheel may be regulated to suit the speed of the received signals, each word received by the relay will appear in the familiar dot and dash characters marked upon the paper strip.

The receiver complete, including the polarized relay, the inking gear, and tape-moving mechanism is known as the Wheatstone recorder.

The received tape is passed to copyists who understand the Morse code, and who translate the characters, writing the message on a received telegram blank by means of a pen or typewriter.

Messages received by the automatic system at any office for relaying to points beyond, may be translated and copied as above described, or the received tape may be passed directly to a Morse operator who transmits the message appearing thereon to destination by hand. If the message is to be forwarded from the relay office over another automatic circuit, the received tape must be translated and the message typewritten, and then repunched on transmitting tape as at the originating office, so that it may be passed through the automatic transmitter connected into the second circuit and sent over the line at high speed.

THE MALLET PERFORATOR

The perforator which is shown in plan and front elevation at *a* and *b*, Fig. 365, is purely mechanical in its action. Groups of perforations corresponding to the letters of the alphabet are made by it in a slip of oiled paper which is afterward propelled automatically through the transmitter.

The keys or plungers, *a*, *a*–1, and *a*–2, actuate five steel punches used in making the desired perforations in the moving band of tape; *a*, corresponding with a "dot," *a*–1, with a space, and *a*–2, with a "dash." The center row of perforations acts as a guide to keep the tape in its proper place in the transmitter and as a rack by which it can be propelled. The perforations above and below the center determine the number and order of the main-line currents sent out from the transmitter.

Figure 365*c* shows the mechanism of the perforator placed underneath the metal cover, and Fig. 365*d* shows the levers *b*, *b*–1, and *b*–2, which are pivoted in the block *B*, under the base, and connected respectively to the keys *a*, *a*–1, and *a*–2. The opposite ends of the levers project upward through the base and terminate at the back of the mechanism near the ends of the five steel punches. Above and below the punches are two small rods provided with steel spiral springs for withdrawing the punches after the depression of the keys. Spiral springs are also used to restore the keys and levers to their normal positions after each operation.

The action of the mechanism in perforating the paper strip is rather difficult to learn from an unavoidably complicated diagram, and it may suffice to observe, for example, that in perforating the word "hat" in the tape the operator depresses the key *a* four times in forming the letter "h" then the

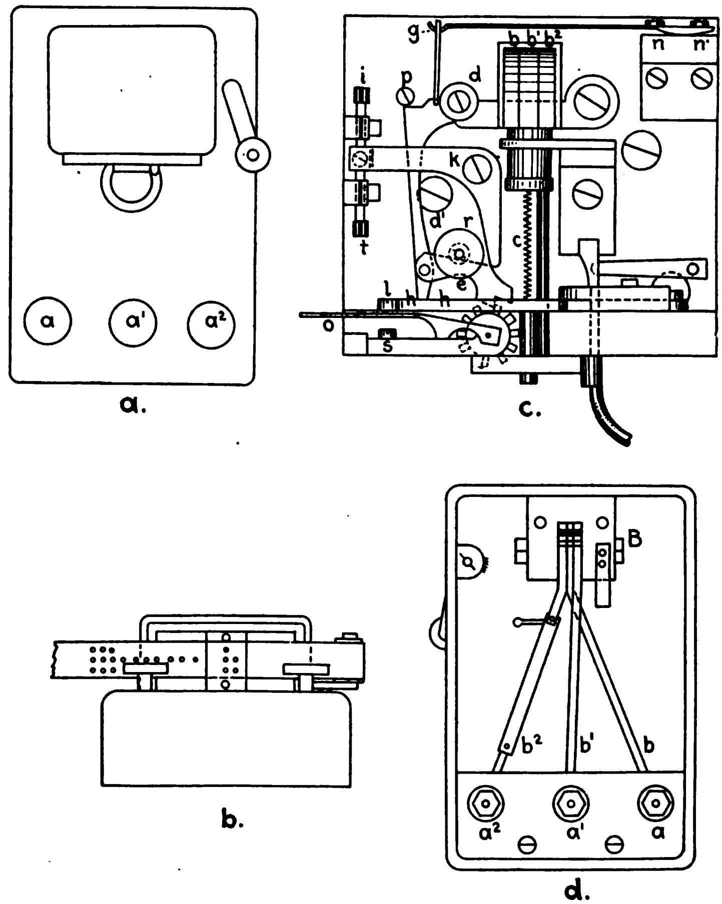


FIG. 365.—Mallet perforator.

key *a* once and the key *a*–2 once in forming the letter "a" and then the key *a*–2 once forming the letter "t." Between each two letters the space key *a*–1 is depressed once and between words twice, in order that the letters and words of the message will be properly spaced and not run together on the receiving tape at the distant station.

ADJUSTMENT OF THE PERFORATOR

The lever *h*, Fig. 365*c*, is connected by means of a small rod passing through the base to the lever *b*–2, and is only actuated when a dash is

punched. Its function is to regulate the movement of the pawl, *e*. When either a dot or a space is punched, the movement of lever *d*–1 is limited by the tail-piece of *h*, and the pawl moves over one tooth only of the star-wheel, pushing the tape one space forward; but when *a*–2 is depressed the lever *h* is raised so that the movement of *d*–1 is not limited by *h*, but by the pin *l*, and the pawl accordingly moves over two teeth of the star-wheel, so that when the key rises the tape advances two spaces.

The instrument is adjusted by means of two screws *i*, *t*, which act upon the bent lever *k*. It must be so adjusted that 120 center guide holes and 120 spaces are produced in exactly 12 in. of paper tape. The adjustment of the screws *i*, *t*, moves the lever *k*, either inward or outward. If the end nearest the punches be moved toward them, then the perforations will be spread over a greater length of tape; but if it be moved away from the punches, the perforations will be closer together and will occupy less space. If a length of slip be taken, containing 121 spacing perforations (which number may be obtained without counting by punching the word "message" four times, including five spaces between words, and seven spaces at the end of the last word), then the distance between the centers of the first and last holes must be 12 in. In other words, the distance between the centers of any two adjacent guide holes must be exactly one-tenth of an inch. Although a perforation more or less will not make any material difference to the working, it is well to adhere to exact spacing when possible; especially is this important when working at high speeds.

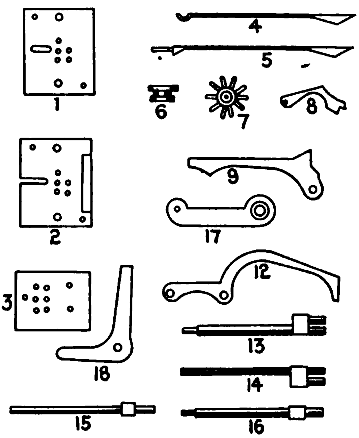


FIG. 366.—Parts of the mallet perforator. 1, Front puncher plate; 2, back puncher plate; 3, back guide to punchers; 4, back spring acting on star wheel click lever; 5, vertical spring on which guide roller is pivoted; 6, guide roller; 7. star wheel; 8, star wheel click; 9, star wheel click lever; 12, lever regulating play of star wheel click lever; 13, center punch (for dot, dash and space); 14, top punch (for dot and dash); 15, bottom punch (2, 1 for dot 1 for dash); 16, center punch (for dash); 17, socket lever; 18, adjusting lever.

The flat spring *g* can be adjusted by means of the screws *n*, *n*–1 and must exert sufficient force to propel the paper freely after each depression of the keys. The vertical spring which carries the small grooved roller, *r*, is adjustable in a similar manner by means of two screws under the base. It should exert just sufficient force to cause the pawl, *e*, to drop between the teeth of the star-wheel. When the keys *a*, or *a*–1, are depressed, the pawl should move freely over one tooth, and when the key *a*–2 is depressed, it

should be drawn back over two teeth of the star-wheel. If undue force be required to produce this action between the pawl and the star-wheel, it will probably be found that the rubber washer under the head of the faulty key is a trifle too thick.

The star-wheel frame is provided with a tail-piece which projects outward through the vertical plate, *o*, on the left-hand side. When paper tape is inserted this tail is pulled toward the operator in order to move the star-wheel out of the way, and as soon as the tail is released, the star-wheel resumes its normal position.

Where two screws are provided for adjusting the lever, care should be taken always to release one before tightening the other, or the heads are liable to be broken off, the thread stripped, or the standards bent. Lock-nut screws, or clamping screws, also, should be loosened before moving the adjusting screws which they clamp, and carefully tightened again after the proper adjustment has been made.

A test gage 1/2 in. wide and 0.009 in. thick should pass freely between the back and front die-plates of the perforator. The standard width of perforator tape is from 0.472 in. to 0.475 in. and its thickness 0.004 in. to 0.0045 in.

Figure 366 shows the various parts of the mallet perforator, each part numbered to correspond with the accompanying list of parts.

KEY-BOARD PERFORATORS

There are several makes of key-board tape perforator on the market, which have been designed to take the place of the mallet perforator in the preparation of tape for transmission by means of automatic transmitters. Among these might be mentioned the Gell used in England and in some of the British colonies, the Kleinschmidt perforator, and the Storm perforator made in the United States. Fig. 367 is a reproduction of a photograph of one of these perforators, which is similar in appearance to all other makes.

Figure 368 shows a key-board arrangement which has been found to answer the requirements of automatic telegraph service.

The Morse characters as they appear in perforations in the tape are shown complete, the alphabet used being American Morse, with the exception of the letter "*L*," which is here shown as consisting of one dot, a space and three short dashes, instead of the regulation long dash of the Morse code.

THE AUTOMATIC TRANSMITTER

Figure 369 shows the mechanical construction and electrical connections of a transmitter arranged to operate a polar relay, the latter serving as a pole-changer in a duplex arranged for automatic transmission.

The movements to and fro of the divided lever *D–U*, are regulated and

FIG. 367.—Keyboard tape-perforator.

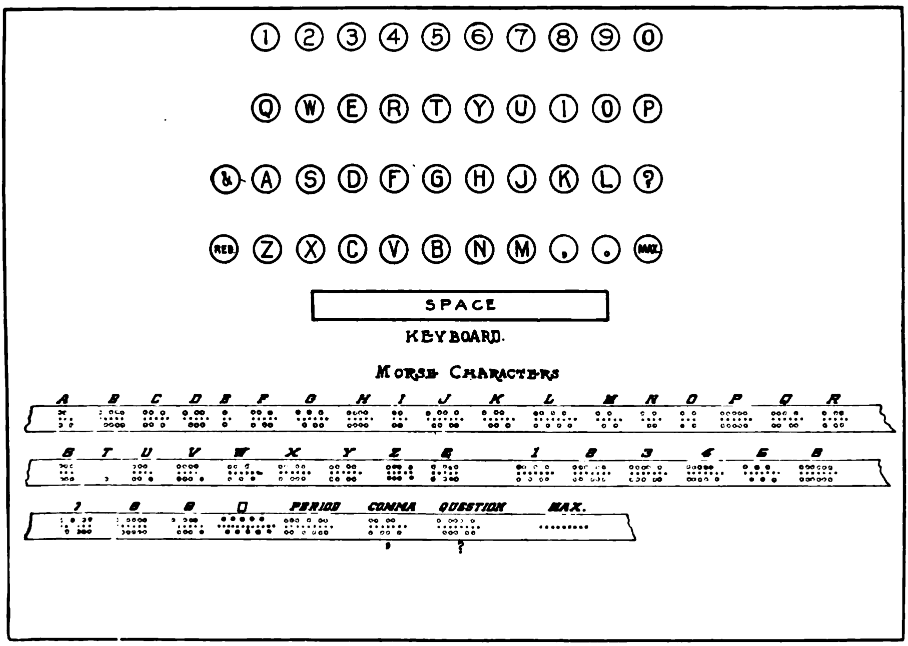


FIG. 368.—Keyboard arrangement of tape perforator, showing specimen of tape after being punched.

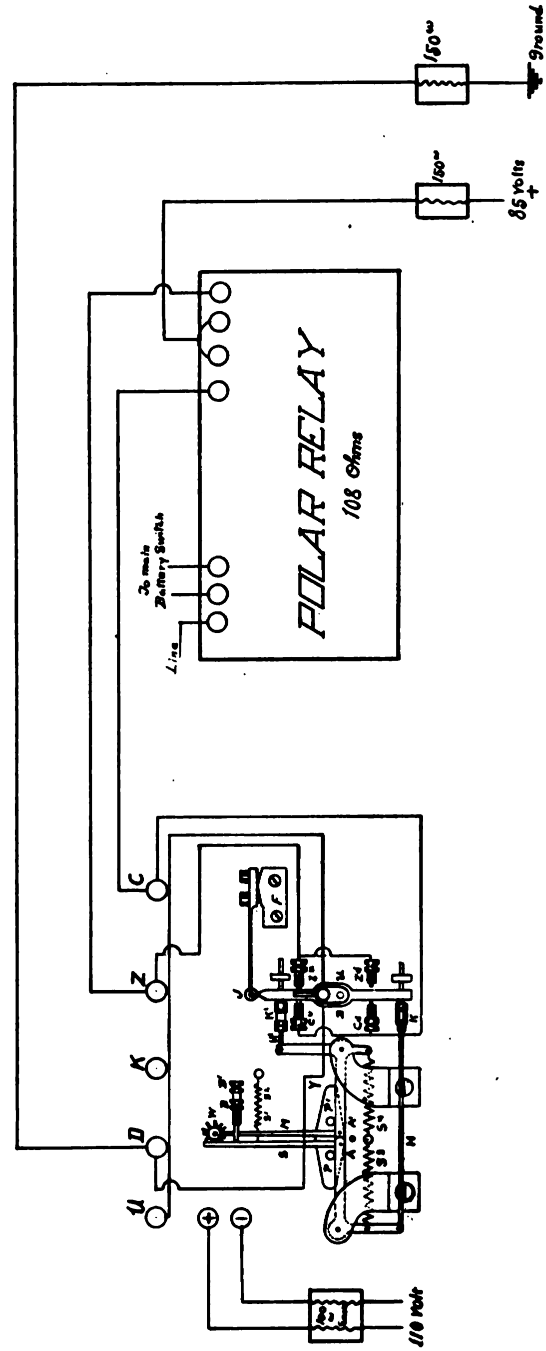


FIG. 369.—Automatic transmitter connected with polar-relay pole-changer.

controlled by the perforated holes in the paper slip, as the latter is moved along from right to left by the star-wheel *W*, above the arms *S* and *M*. The transmitter is constructed so that it may be connected directly to line, the contact points *Cu–Cd* and *Zu–Zd* acting as the duplex battery terminals and the divided lever as the pole-changer tongue connected to the main-line wire, but it has been found that the ranges of adjustment are not so limited where the automatic transmitter is employed to operate locally a polar relay, the tongue of which is connected to line and the local contact points of which carry the main-line potentials, plus and minus. The upper and lower halves of the divided lever *D–U* are mechanically connected, but separated electrically, that is, one is insulated from the other, so that either the lever *D*, or the lever *U*, in connection with the lower or upper contact points respectively *Cd–Zd*, or *Cu–Zu*, may be used to operate the line instrument. In case the operation is transferred from the upper to the lower contacts, or *vice versa*, the only alteration in connections required is that the ground contact be transferred from transmitter binding-post *U* to *D* or *D* to *U*, as the case may be.

The significance of the letters *D* and *U* may be borne in mind by noting that *U* refers to the upper pair of contacts, and *D* "down" or lower pair.

The rocking beam is equipped with two pins *P*, *P'*, which project outwardly. The revolution of a driving wheel (within the case of the instrument and not shown) which is fitted with a projecting pin near its periphery, causes the rocking beam to move up and down alternately upon a central pivot. The pivoted cranks *A* and *A'* are held against the under side of pins *P* and *P'* by springs attached at right angles to the lower extremities of the cranks. Rising from the ends of the two cranks are the rods *S* and *M*. Actually, the rods are side by side, one on each side of the star-wheel *W*. In the sketch the position of one of them has been changed somewhat in order to show both rods. Two adjustable screws *B* and *B'* regulate the distance backward at which the rods may be set, the springs *S'* and S^2 holding the rods against the screws. In their upward movement the rods pass through slots cut in a brass platform. As the perforated tape is moved along the platform by the star-wheel, the rods continuously moving up and down enter the holes in either side of the tape directly as these holes appear over the rods. Above the star-wheel is mounted another wheel a trifle wider than the tape which acts to hold the tape down and permits the projections of the star-wheel to enter the center row of holes in the tape and thus propel it forward.

With the transmitter running free, that is without tape, rods *S* and *M*, in response to the movements of the rocking aim, rise and fall alternately. The lower extremity of the upright section of crank *A* moves to the right when the rod *S* moves upward; this action pushes the lever acting between the contact points to the right by means of the rod and boss *K*. The up-

ward movement of the rod *M* in the same manner causes *K* to push the lever *U* to the right. Were the transmitter connected directly to line, this action would mean that a "make" or marking current would go to line at the instant the rod *M* rises, and a spacing current would be sent to line when the rod *S* rises. Thus, with the transmitter running without tape, a series of reversals are sent out producing "dots" in the distant polar relay.

Inserting a strip of perforated tape in the transmitter results as follows: Assuming that the marking rod *M* has risen and entered a hole in the tape and that the tape moves forward three or four spaces before a perforated hole appears above the rod *S*, then the marking current will be continued until the spacing rod *S* has an opportunity to rise. It is obvious that the rod *S* has in the meantime continuously bombarded the tape, awaiting the first opportunity to travel over its full course in response to the tension of the spring S_3 and which it has been prevented from doing by having presented before it a portion of the tape in which no perforations have been made.

As in the regulation polar relay, the lever of the transmitter must remain on either closed or open-contact point. In the polar relay this is brought about by employing permanent magnets to hold the armature in either position. In the transmitter the same thing is accomplished by the jockey wheel *J*. It is evident that as the lever moves to the right or left it is held in either position by the action of the spring bearing down the jockey wheel.

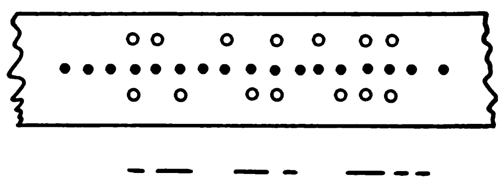


FIG. 370.—Specimen of perforated tape bearing the word "and."

Figure 370 shows a sketch of the perforated slip required to transmit the word "and." The upper holes are those engaged by the rod *M* and the lower ones by the rod *S*. When the tape is in proper position in the transmitter the lower holes are on the outward side, or toward the attendant, the tape moving from right to left.

When unpunched paper is inserted, both rods *S* and *M* are pressed downward and the pins *P*, *P′*, in their motion do not actuate the crank levers *A*, *A′*; the lever *DU*, consequently, does not move and a permanent current is therefore sent to line.

If now, slip, perforated, say, with the letter $\overset{\text{O O}}{\underset{\text{O \ O}}{\circ\circ\circ}}$ (a) be inserted, then, when rod *M* rises, it will be free to pass through the first upper hole, and the lever *DU* will be moved and will send out a "marking" current. When the reverse movement of the rocking beam *Y* takes place, rod *S* will be free to pass through the first lower hole, and the current sent by *DU* will be reversed; a *dot* will therefore have been sent. On the next movement of the rocking beam, *M* will be free to pass through the second upper hole, and the length

of the "spacing" current is consequently precisely equal to that of the previous "marking" current (*dot*). The "marking" current being now to line, when the rocking beam leaves *S* free to rise, it is prevented from so doing by the paper, which is not perforated below the second upper hole. In this case, therefore, the "marking" current is kept on until the rod *S* is again free to rise, which it can do through the second lower hole, and the current is then reversed. It will be seen that the "marking" current is kept to line during movements equal to two dots and the space between, this being the established length of a dash. It is clear, therefore, that when correctly perforated slip is run through the transmitter any required Morse signals—dots, dashes and spaces—can be automatically sent to line.

Adjustment: One end of the flat spring which carries the jockey wheel *J*, is attached to a brass piece *F*, which is in turn screwed rigidly to the frame of the gearing. The upper side of *F* is V-shaped, and the tension of the spring is adjustable by means of the two screws which fasten it to its support. It should have sufficient tension to enable it to push the lever *DU* suddenly to the right or left when either of the collets *K* or *K'* push it beyond the center of the jockey wheel.

The collets *K* and *K'* can be adjusted by being screwed forward or backward; their correct position may be found by running the transmitter with a blank slip, when the bar should remain unaffected, whether resting in its right or left position. The collets must, however, be sufficiently close to push the bar over the center when the slip is removed, so as to allow the jockey roller to complete the movement.

In order to insure reliable action at high speed, it is essential that the spiral springs *s*–3 and *s*–4 be strong enough to easily overcome the tension of the flat spring acting through the jockey wheel upon the lever. The amount of play allowed between the contact screw *C–d* and the lever *D* when it is resting on *Z–d*, or *vice versa*, is about 5 mils. The contacts *C–u* and *Z–u* should be adjusted to suit, so as to preserve similar distances with respect to *U*.

The exact positions of the vertical rods *S* and *M* are regulated by the screws *B*, *B'*; each of the rods should be so adjusted that it commences to enter a perforation in the slip when the left-hand edge of the perforation is sufficiently clear of the left-hand edge of the rod to allow it to pass through freely. If the screws *P* or *P'* are screwed too much either way out of their correct position, the rods will catch against the edges of the perforation, and the mechanism will not act properly.

The springs *S*–1 and *S*–2 pull the rods *S*, *M*, back against the screws *P*, *P'*, when they have become sufficiently withdrawn to be just clear of the slip. Although these springs are very light, they must be strong enough to cause the rods to return to their normal positions promptly.

THE MOTIVE POWER OF THE WHEATSTONE TRANSMITTER

Until recently, high-speed transmitters have been operated by weight-driven gears, and while this method permitted the employment of the high-speed system at small offices not equipped with sources of electric power when upon occasion a small office was called upon to handle for a few days a large volume of business, in large offices where automatic equipment is permanently located it is desirable to have transmitters which are driven by electric motors, first, to obviate winding up the weight, and second to obtain constant speeds.

Transmitters are equipped with small direct-current motors which are run at constant speed, approximately the maximum speed of the motor. No motor-control rheostat is used. An extension of the motor shaft is fitted with a metal disk which acts as a friction plate. On the face of this friction plate rests the edge of another small disk made up of compressed rawhide held rigidly between two brass plates by means of which the disk is securely attached to its axle. The end of the armature shaft remote from the friction plate is fitted with two tension-springs which act to hold the plate in contact with the rawhide disk. The axle of the disk has on one end a pinion gear which operates the driving axle of the transmitter by means of a clutch. The opposite end of the axle bearing the rawhide disk is hollowed out cone-shaped in order to engage the point of the adjusting screw which determines the position of the rawhide disk on the face of the friction plate. The method of regulating the speed of the transmitter is founded on the principle that the speed through space of various points from center to periphery of a revolving wheel, is greatest at the periphery and least at the center. The speed-regulating screw as it moves the axle of the friction disk along, results in the friction disk being pushed nearer to the periphery of the friction plate, thus increasing the speed of rotation of the transmitter driving axle.

As there is no spring used to withdraw the axle of the rawhide disk when it is desired to reduce the speed by causing the disk to take up a position nearer the center of the friction plate, it is evident that another property of the revolving wheel is availed of to accomplish the desired end.

It is well known that the upper half of a revolving disk or wheel has a motion in the reverse direction to that of the lower half and any device in frictional contact with the side of the wheel, unless restrained, takes on a motion of translation of that portion of the wheel with which it is in contact, thus when the adjusting screw which holds the friction disk up to its work, is withdrawn the natural tendency is for the friction disk to move inward toward the center of the friction plate and the speed is gradually reduced.

The clock-work gearing which drives the moving contacts of the transmitter proper is connected with the driving axle by means of a universal clutch. The transmitter proper is detachable from the base, the armature and battery-contact wiring being made to buffer contacts. When the transmitter gets out

of adjustment and there is a spare unit available it requires but 10 or 12 seconds to remove the defective instrument and substitute one known to be in working order. As the transmitter is set in place the buffer contacts engage their corresponding projecting terminal points and the driving clutch engages the driving axle without any action on the part of the attendant except that he place the transmitter in proper position on its brass bed-plate and tighten the thumbscrews.

Where 110-volt current is available, it is customary to use it for the operation of the transmitter motor. The regulation of the speed of the transmitter (and consequently of the speed of transmission) is accomplished by means of the friction drive. A hard rubber knob mounted on one side of the transmitter

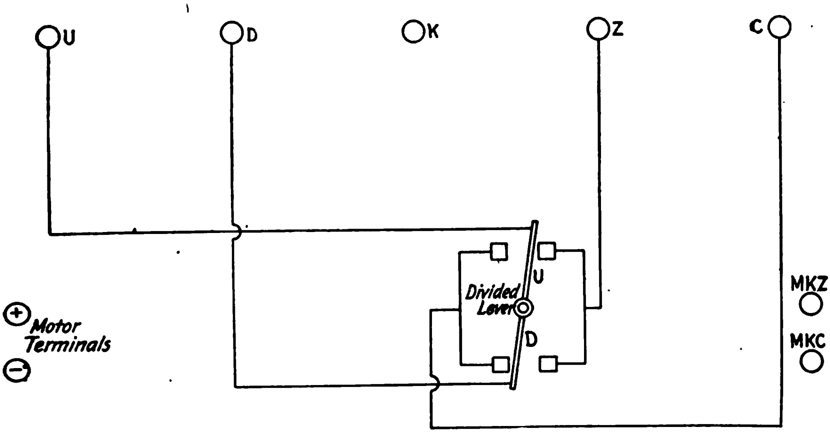


FIG. 371.—Main line and battery connections of the automatic transmitter.

case, accessible to the attendant, permits of regulating the speed at which signals are sent over the line, ranging from 10 words per minute to 300 words per minute.

As there is no rheostat control of the motor circuit, it is well to have a resistance of about 100 ohms in each side of the 110-volt circuit to prevent heating of the motor.

Revolving the shaft of the motor causes the rocking beam of the transmitter to move up and down at a speed corresponding to the speed at which the star-wheel forwards the paper strip. These two related movements are accomplished by means of suitable clock-work gearing.

Figure 371 shows an enlarged view of the transmitter main connections, where the automatic transmitter is employed to operate a pole-changer in the form of a standard polar relay. The terminals *K*, *MKC*, and *MKZ* are not used except when the duplex line potentials are connected directly to the transmitter. The terminals marked − and + show where the 110-volt motor leads are to be connected. When a polar relay is used to control the

line battery, the main-line and artificial-line binding posts of the relay are connected to the terminals *Z* and *C*, and the terminal *U* or *D* is grounded. Either the upper or lower contacts may be used by changing the ground connection from *U* to *D*, or *vice versa*.

The Wheatstone system has for many years been used on certain lines of the Western Union Telegraph Company, and within the past year or two has been introduced on the lines of the Canadian Pacific Railway Telegraph system, in the operation of a Pacific cable circuit between Montreal, Que., and Bamfield, B. C., with repeaters at Fort William, Ontario, 995 miles from Montreal, and at Calgary, Alberta, 1,256 miles distant from Fort William, also at Vancouver, B. C., 646 miles from Calgary. The distance from Vancouver to Bamfield is 115 miles, including 80 miles of submarine cable. At Montreal dynamo current is used; at Fort William, Calgary and Vancouver, storage battery is used, and at Bamfield, gravity battery.

On the Pacific cable circuit, overland through Canada, the question of speed is of secondary importance, and high speeds of transmission are not aimed at. The principal object in employing the Wheatstone system is to insure accuracy. Also, a material advantage accrues from the fact that at a given speed in words per minute, Wheatstone signals on account of their evenness and regularity, "carry" much better over long circuits than do hand signals at the same speed, resulting in fewer calls for repetition of doubtful words or letters.

At a speed of, say, 40 words per minute, using Wheatstone transmission, the total amount of business handled over a circuit in a day exceeds considerably the amount of business that would be handled during the same period by means of the Morse key; where the sending operator does not exceed a speed of, say, 40 words per minute. This is due to the fact that in Wheatstone working there is generally 2 or 3 ft. of slack tape which has been perforated, between the perforating machine and the transmitter, so that the frequent stops made, from one cause or another, by the perforator operator—the sender—do not interrupt the continuity of line transmission, which goes on continuously as long as tape is fed to the transmitter.

Wheatstone working may be applied to any polar duplex, or polar side of a quadruplex, by providing a three-point switch at each sending end for the purpose of switching the automatic transmitter, or the Morse key into circuit as desired, and by providing a similar switch at each receiving end for the purpose of switching the line wire into the automatic recorder, or the regular polar relay as desired.

Where speeds above 150 words per minute are to be maintained, it is necessary to use at the terminal offices and at repeater stations the most efficient and "fastest" polar relays obtainable, otherwise the equipment and connections of the Wheatstone automatic duplex are the same as those of the high efficiency duplex (see Fig. 237).

THE POSTAL AUTOMATIC

The Postal Automatic Telegraph System is identical with the Wheatstone in so far as concerns the preparation of the transmitting tape, and the transmission of the signals; but the reception of the signals is accomplished in an entirely different manner, being received by an electromagnetic punch, or "reperforator" which, instead of marking the dots and dashes of the letters on the receiving tape with ink, as in the Wheatstone system, perforates the characters in a continuously moving strip of paper tape, the received tape resembling the transmitting tape, inasmuch as the Morse characters appear thereon in a series of perforations. The improvement in this method as compared with Wheatstone recorder reception, is that the received tape may be passed through a local "reproducer," and the messages copied by ear from an ordinary sounder.

The reproducers are motor driven and are under the control of the reproducing operator so that the speed of reproduction may be regulated to accord with the ability of the operator. At his convenience the tape may be stopped, pulled back and run through again for the purpose of confirming doubtful words. In practice, therefore, the reproducing operator copies from a "sender" over whom he has absolute control in the matter of speed and of repetition. Moreover, with this system, messages received at relay offices for points beyond, which are equipped with automatic apparatus, may be relayed automatically, simply by passing the received tape through an automatic transmitter of the reproducer type. In this case the reproducer operates the duplex pole-changer in the same way as it operates the sounder for local reproduction.

The Reperforator.—The operation of the receiving punch, or reperforator, will be understood by tracing the receiving circuits shown theoretically in Fig. 372.

It will be observed that here the main-line polar relay of a duplex instead of operating locally a reading sounder, as is customary in ordinary duplex working, operates an extra polar relay, the armature lever of which is grounded through a 6-m.f. adjustable condenser. Two double-spool electromagnets, M, M', of the reperforator have circuits leading through their windings from 200-volt dynamos of each polarity, thence, extending to the open and closed contact points respectively of an auxiliary polar relay. The "punch" magnets control the movements of two armatures which on their free ends are equipped with steel punches, P, P, about 1/16 in. in diameter, and 1 in. long, which when the magnets are energized are driven through holes (h, h, Fig. 373) in a die plate, and perforate holes in a strip of paper which is being drawn through a slot past the holes in the die plate, the slot being just large enough to permit free passage of the tape.

The tape is moved forward continuously by means of a tape-transmission

and take-up gear, operated by an electric motor the speed of which is regulated by a small hand rheostat.

It is customary to adjust the receiver from hand sending at the distant station, before the automatic transmitter is connected to line. A closed key, sending a marking current from the distant station, results in the tongue of the home main-line relay moving over to its front contact, thereby presenting a ground contact to the 85-volt dynamo circuit by way of the front contact of the main-line relay, and the magnet *EM* of the auxiliary relay, which causes the latter to attract its armature to the left, permitting the 6-m.f. condenser to empty itself of the negative charge which it had accumulated while the tongue of the auxiliary relay was in contact with the negative battery terminal. The process of reversing the charge held by the condenser

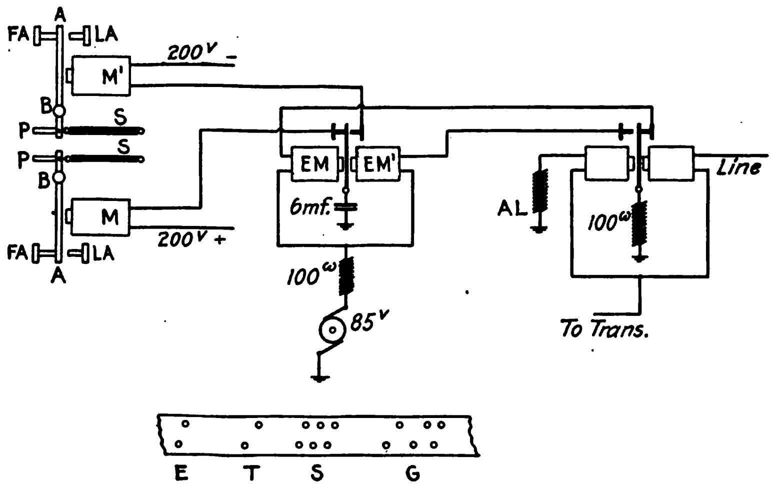


FIG. 372.—Theory of the reperforator.

from negative to positive, after the relay tongue makes contact with the positive battery terminal, causes the magnet *M* to momentarily attract its armature *A*, and as the armature lever is pivoted at *B*, the steel punch *P* is driven through the moving strip of paper, perforating a hole near the lower edge of the tape. As the distant key is opened and a spacing current sent to line, the home line-relay "opens," thereby transferring the ground contact presented to the 85-volt dynamo circuit, through the magnet *EM'* of the auxiliary relay, causing the lever of that relay to move into contact with the opposite local contact, whereupon the charge held by the condenser is changed from positive to negative, causing momentary magnetization of the punch magnet *M'*, the result of which is that the armature lever actuating the upper steel punch, drives the latter through the tape, perforating a hole near its upper edge. The horizontal distance between the two holes depends upon

the time elapsing between the instant the marking current is sent out and the time the spacing current is sent from the distant station. If the positive and negative battery contacts made by the distant pole-changer are made close together, as in forming the letter "e," the holes in the received tape appear as at "e" in the specimen slip, Fig. 372. If a greater period of time separates the positive and negative battery applications, as in forming the letter "t," the holes in the receiving tape appear as at "t," in the specimen slip.

The steel punches are adjusted to travel forward just far enough to go through the paper and make a clean round hole, and backward just far enough to clear the face of the die-plate.

In view of the fact that the tape is passing continuously through the slot in front of the steel punches, the act of punching the holes must be accomplished by extremely rapid movement of the punches so that there will be no tendency to tear the tape. The speed at which the punches move forward and backward in response to the operation of the auxiliary relay is regulated by having the capacity of the condenser accurately adjusted, and by adjusting the tension of the strong retractile springs *S*, attached to the armature levers of the reperforator, so that when the steel punches are traveling the required distance to and fro, the action will be rapid and snappy.

It is evident that the tape being perforated is stopped each time either the upper or lower punch is in the act of perforating a hole, and as each punch is operated many times per second, it is necessary so to adjust the tape-moving mechanism that these momentary stoppages are compensated for by "slip" in that part of the gear which pulls the tape through the slot.

The instruments have been designed to do this satisfactorily, and it has been found that attendants can, with little practice, learn the correct adjustment. The present method of taking care of the received tape coming from the reperforator is the same as that used in caring for the original transmission tape as turned out by the Wheatstone perforator, that is, by rolling it up by hand as it comes from the receiver.

The receiver when in operation requires the constant attention of an attendant, and it is quite convenient for him to take care of the received tape in the manner above referred to. The received tape may be parceled out in units of one message, two messages, or in any number required by traffic conditions, as the receiver attendant very quickly learns to read the tape and is able to follow the wording as perforated thereon. The end of each message is signified by a paragraph sign (––––) or by a succession of letters "a," without space between them.

The code used is the Morse alphabet, except that the letter "L" is changed from "long dash" (—), to "dot, three dashes," (·–––), and the figure "nought" from "long dash" to five short dashes (–––––).

The received tape is passed to the reproducing operators in whatever size bundles the traffic demands, and by them is run through local repro-

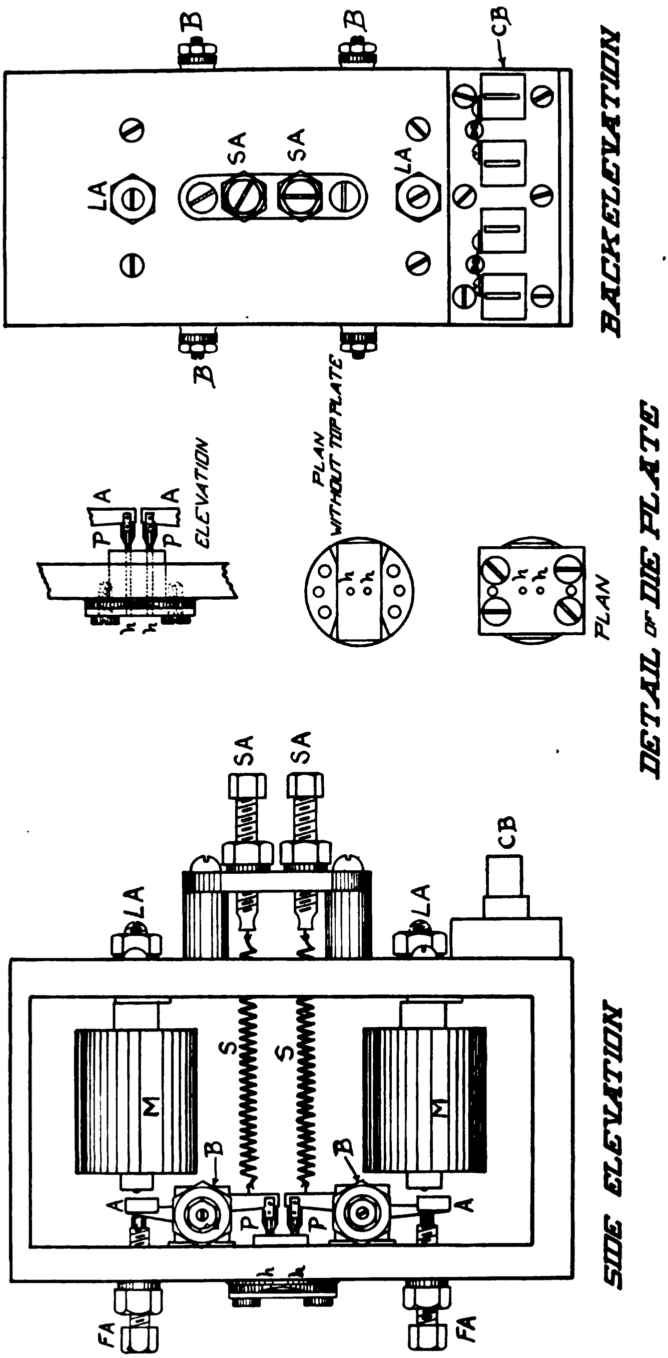


FIG. 373.—Actual construction of the reperforator.

ducing machines at a speed to suit the convenience of the operator as before stated.

The operation of the reproducers is quite simple, and may be learned by any Morse operator in a short time and without difficulty.

Figure 373 shows the actual construction of the reperforator used in connection with the Postal automatic telegraph system, the various parts bearing the same index letters as do the same parts illustrated in the theoretical diagram, Fig. 372. The spring adjustments *SA*, are for regulating the retractile tension exerted by the springs *S*, upon the armature levers *A*. The front adjustment screws *FA* act as back-stops for the armature levers, and must be so set that the steel punches fastened to opposite ends of the levers, when pulled back by the springs, will come to rest in the punch guide holes *h*, just clear of the face of the die-plate. The lever adjustment screws *LA* extend between the two spools of each magnet, projecting far enough to prevent the armature striking the cores of the magnet, and also serve as adjustments for regulating the distance beyond the face of the die-plate the punches *P* are allowed to travel. The forward and the backward travel of the steel punches, therefore, is regulated by means of the adjusting screws *FA* and *LA*. In practice, a forward travel, from rest, of 0.006 in. is all that can be allowed where high speeds are to be maintained.

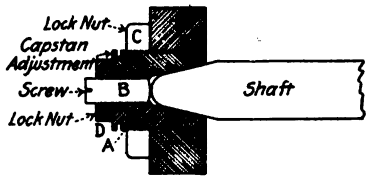


FIG. 374.—Reperforator bearing adjustment.

Figure 374 shows an enlarged view of the armature-shaft bearing of the reperforator. The successful operation of the reperforator is largely dependent upon the elimination of lost motion in the shaft bearings, and the bearing employed while somewhat elaborate is the only one among those tried out which satisfactorily answers the purpose.

The parts of the bearing are made of the hardest grade of Tobin bronze, and the adjustment is made as follows:

To adjust bearing: Disconnect retractile spring from armature lever. Tighten screw *A*, leaving just space enough between its inner surface and the surface of the shaft to hold a film of oil. Tighten screw *B* of each bearing so that when the steel punches are properly lined up in the punch guide holes the play of the shaft will be equal in the bearing *A* on each side of the shaft. Lock-nut *C* should then be tightened, securing the adjustment of *A*, care being taken not to disturb *A* after being properly set.

The reperforator as here described is the invention of Mr. F. E. d'Humy.

Figure 375 shows the transmitter circuits, arranged so that either the high-speed automatic transmitter, or a Morse key operating an ordinary pole-changer may be switched into circuit, depending upon the position of the

lever of the switch on the right. The duplex "balancing" switch is shown on the left.

A reading sounder circuit for the out-going signals is provided by means

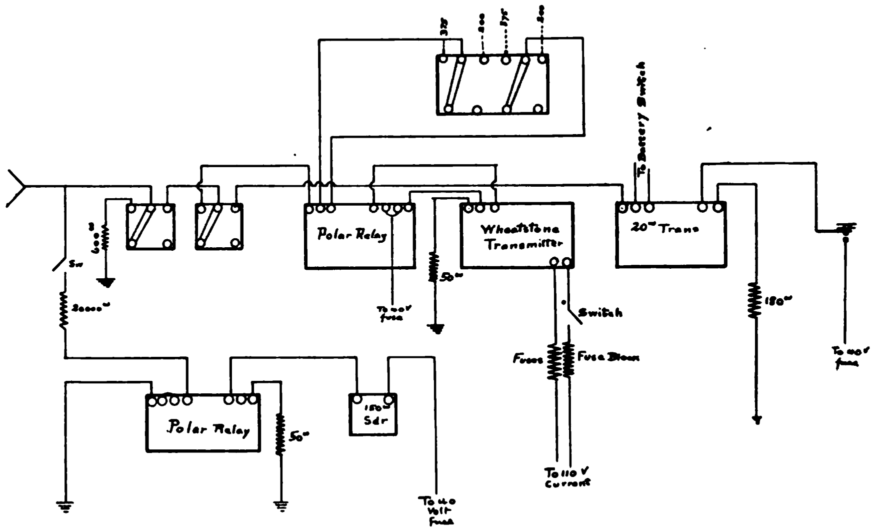


FIG. 375.—Transmitting circuits, Postal automatic.

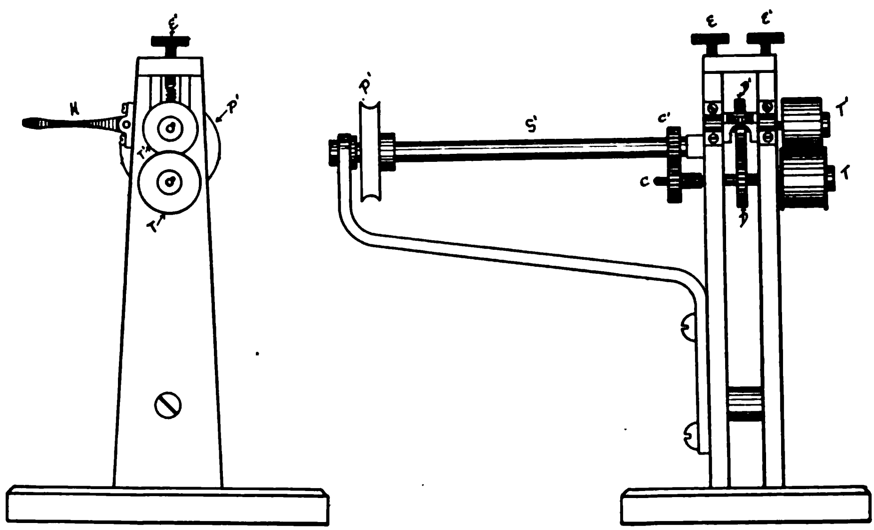


FIG. 376.—Tape take-up gear, Postal automatic.

of a 20,000-ohm leak to earth through a polar relay as shown in the lower left-hand portion of the diagram. After the speed of transmission is run up higher than 65 or 75 words per minute, the sounder, of course, fails to record the signals intelligibly.

Figure 376 shows the construction of the tape take-up gear.

The receiving tape is fed to the reperforator by a tape transmission device, the speed of which may be regulated to suit the speed of signaling. As the perforated tape leaves the reperforator it passes between the rollers *T*, *T'*, of the take-up gear, which are in light contact with each other, the degree of tension being adjustable by means of the compression-spring screws *E*, *E'*. A spring belt extends from the pulley P' to a pulley mounted on a shaft which is geared to the driving mechanism of the tape-transmission

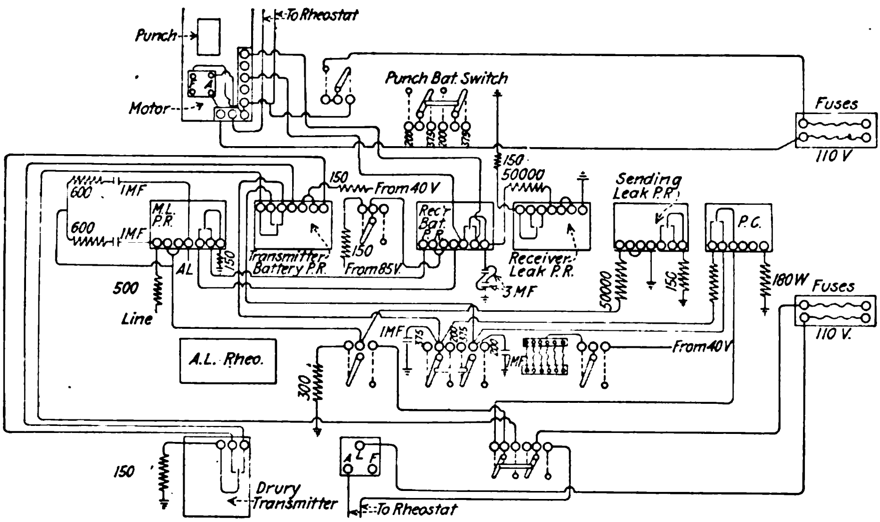


FIG. 377.—Complete wiring connections of sending and receiving circuits. Postal automatic.

gear (not shown), and the speed ratios are such that the rollers *T*, *T'*, of the take-up, revolve three times as fast as the feed rollers of the transmission device, which means that the "pull" of the rollers *T*, *T'*, is not positive or constant. It is necessary that there shall be considerable "slip" of the tape as it passes through the rollers of the take-up, for, if the pull were positive the tape would be torn during the brief instant that either of the steel punches of the reperforator are punching a hole in the tape. The combined "slip" of the spring belt and of the rollers *T*, *T'* compensates for the many stoppages of the tape which take place during the operations of punching.

Figure 377 shows the wiring and binding-post connections of both transmitting and receiving circuits of the Postal automatic arranged for duplex operation.

PRINTING TELEGRAPHS

Although the subject of printing telegraphs is an old one with the inventor and with the promoter, the development of satisfactory printing telegraph

systems has not reached that stage where the subject is in shape for practical consideration in a work dealing with telegraph practice.

The reason for this (so far as the employment of printing telegraph systems in America is concerned) is that the systems which have been tried out, and which at the present time are in service, have been operated by the inventors themselves, or under their direction, and in some cases by specially trained staffs, recruited, largely, from mechanics who know little or nothing about Morse telegraphy.

On account of the many mechanical movements involved in the operation of telegraph printers, these machines are necessarily somewhat complicated in construction, and although in their design great ingenuity has been exercised in applying known laws and principles of mechanics, the apparatus produced, to do its best work, must be handled by competent mechanics. In most of the systems so far introduced, the purely electrical features, such as line-potential and line-current values, and main-line relay and transmitter functions, are comparatively simple, and it is with these features only that the Morse telegrapher has been concerned.

When a new system is tried out in service, apparently it has been a much easier matter to teach mechanics what they need know about the electrical features involved, than to teach the expert telegrapher what he must know about mechanics, in order to operate the printer efficiently. These considerations, in a sense, isolate the subject of printing telegraphs from the subject of Morse telegraphy.

It is not to be inferred, however, that printing telegraph systems cannot be employed to the advantage of the service, as it is quite possible that the time may arrive when a large portion of the telegraph traffic of this country will be handled by means of printing telegraph systems, and it is possible that within a few years, one, two, or more systems will have reached a stage of development and of standardization, that will make possible a technical treatment of the subject from a telegraphic standpoint that will be intelligible to Morse operatives.

NAMES OF PRINTING TELEGRAPH SYSTEMS INVENTED, TRIED OUT, AND IN SERVICE

Two different systems, known as the Rowland and the Wright, have within the past few years been tried out experimentally on the lines of the Postal Telegraph-Cable Company. Each of these systems was the product of printing telegraph inventors of great skill, and who were quite familiar with the requirements of such inventions.

The performance of the Rowland system and of the Wright system was excellent under certain conditions of traffic, but both have been taken out of actual service and returned to the laboratory for further development.

The Western Union Telegraph Company has for a number of years past been using a printing telegraph system known as the Barclay printer. Formerly the system was known as the Buckingham, in which certain changes and improvements have been made by Mr. Barclay.

The Buckingham-Barclay printer is at the present time employed commercially by the Western Union Company, but is still being studied with the object of introducing further improvements, or of making alterations, in order that the machine may more satisfactorily meet the requirements of modern telegraph traffic conditions.

In British Post-office telegraph service, the following named systems are being used to a greater or less extent: The Creed, Murray, Baudot, and the Hughes.

In the United States at the present time a printing telegraph system known as the Morkrum, is being tried out on certain lines of the Postal Telegraph-Cable Company, and of the Western Union Telegraph Company.

In Canada the Morkrum system is being tried out on a Canadian Pacific Railway-telegraph circuit between Montreal and Toronto.

For the information of those who may wish to study the historical development of printing telegraph systems, or who may desire to investigate the principles of operation, and the construction of printing telegraph machines, a condensed bibliography of printing telegraph literature is incorporated in the appendix, see section A.

CHAPTER XXI

TELEGRAPH AND TELEPHONE CIRCUITS AS AFFECTED BY NEIGHBORING ALTERNATING-CURRENT LINES

TRANSPOSITION OF LINES USED FOR TELEPHONE PURPOSES AND FOR SIMULTANEOUS TELEGRAPH AND TELEPHONE PURPOSES

It is well known that when current flows in any wire, there exists in the space surrounding the conductor an electromagnetic field, extending outward from the wire to an indefinite distance and gradually diminishing in strength. If the current traversing the conductor is alternating in polarity, the strength of the electromagnetic field is continually changing, and it is due to this change in strength that electromotive forces are induced in neighboring conductors.

Due to the sign of the e.m.f. and its value in the first-mentioned conductor, there is an electrostatic field extending from it to an indefinite distance which decreases in strength with increased distance. The electrostatic field induces charges in adjacent conductors; the induced charge continually changing in sign—from positive to negative and *vice versa*—so that in effect there is induced in the neighboring wire an alternating current as a result of both electromagnetic and electrostatic induction.

It is true, of course, that electrostatic and electromagnetic fields exist in the space surrounding conductors carrying direct, or uni-directional currents; but in this case it is only the rise and fall of the current strength, with the accompanying rise and fall of the field strength (generally as a result of opening and closing the circuit) which induces disturbing currents in neighboring conductors.

The disturbance created, so far as the effects of electrostatic and electromagnetic induction are concerned, in the case of the former depends upon the distribution of the currents of charge, which is proportional to the rate at which the electrostatic field changes. In the case of the latter the neighboring wire has induced in it an electromotive force proportional to the rate at which the strength of the electromagnetic field changes.

In the operation of telegraph circuits the induced disturbances resulting from the proximity of the conductor to other conductors carrying direct currents, generally are due to cross-fire between neighboring conductors of the telegraph system on the same pole lines (see Cross-Fire, page 209). Those disturbances due to atmospheric electrical phenomena also have been referred to in a previous chapter, see page 120.

The most harmful induction experienced in the operation of telegraph lines is that due to neighboring high-tension power lines carrying alternating currents.

Numerous plans for obviating the effects of induction from high-voltage alternating-current power lines have been suggested, some of which have been tried out in practice, the results in most cases being far from satisfactory.

There are, however, a few methods of getting around the difficulty, which have considerable merit, and which when properly applied make possible the operation of circuits subject to inductive disturbances, which, otherwise would be inoperative as long as the physical relations of the two lines remained unaltered.

One of these methods requires that two wires be used for each telegraph circuit, thus forming a metallic circuit in place of the usual single grounded conductor (see Fig. 266, "The Metallic Circuit Quadruplex").

Among the other methods proposed, might be mentioned those covered by U. S. patents, Nos. 955,141 and 955,142, issued to Mr. Minor M. Davis. The first covers the placing of an idle conductor in close proximity to a telegraph conductor so that both of these conductors are subject to the induction from the disturbing source, and affected to the same extent. The currents induced in the idle conductor will react upon the telegraph conductor and this reaction may be adjusted so as to compensate or neutralize the action of the disturbing circuit upon the telegraph conductor. Or, stated specifically, a positive impulse in the disturbing wire induces a negative impulse in the telegraph wire and also in the idle conductor, the negative impulse in the idle conductor reacts tending to produce a positive impulse in the telegraph circuit. By regulating the resistance and capacity of the idle conductor, the impulses resulting from the reaction of the idle conductor may be made to counteract the disturbing impulses in the telegraph circuit.

This plan of induction neutralization is especially applicable to telegraph conductors in aerial cables suspended on pole lines parallel to high-tension lines. To attain the desired ends the telegraph wires extending through the zone of disturbance may be cabled. The conductors in the cable consisting of two groups arranged parallel and insulated from each other. The wires of one of these groups being used for signaling purposes while the other group of wires—the idle conductors—are tied together at each end of the cable. At one end of the cable the joined idle conductors are connected to ground through an adjustable resistance, and at the other end of the cable to ground through an adjustable capacity.

With this arrangement a positive impulse in the disturbing wire induces an impulse of the opposite sign in all of the conductors in the cable. If the resistance and the capacity of the idle conductors is properly adjusted this negative impulse will be so proportioned in its effect upon the telegraph conductors that the induced impulse from the disturbing wire will be neu-

tralized. Obviously, the idle conductor does not need to be as long as the telegraph wire, but by establishing the constants of the idle conductors—capacity and resistance—at the most effective values, an effect is produced which tends to compensate for the effect of the disturbing wire upon the telegraph conductor.

The other plan aims to neutralize induction in parallel circuits by employing as a conductor the metal sheath of the cable inclosing the telegraph conductors and a parallel compensating conductor, all of which are subject to the same inductive influence, and causing the induced impulses in the compensating conductor to react upon the telegraph conductor to an equal and opposite extent as compared with the disturbing cause.

Where there are one or more insulated conductors in parallel relation, connected in circuit with telegraph apparatus in the ordinary manner, parallel or with these conductors, as in the same cable, are one or more compensating conductors; these are connected in a circuit susceptible of conveying induced impulses, and for this purpose there may be used a ground return circuit, or the circuit may include a condenser. One coil of a transformer is connected in this circuit and the other coil of the transforner is connected in circuit with a conductor arranged parallel with the disturbing source, for this purpose there may be used a separate conductor or the metal sheath or armor of the cable included in a compensating circuit may be used, and the transformer so adjusted that the compensating conductors will develop a source of alternating current having an electromotive force efficient to compensate for the inductive effect of the disturbing source. If the disturbing source extends parallel to the telegraph conductors for a comparatively long distance there may be one or more compensating conductors arranged parallel with the telegraph conductors for a much shorter distance, but the electromotive force, intensity or current strength is increased, graduated or adjusted so as to compensate and neutralize the effect of the disturbing cause in the telegraph conductors.

An effective and inexpensive method of screening the Morse relays in a grounded telegraph circuit from the effects of induction from a neighboring high-tension line is illustrated schematically in Fig. 378.

At each end of the section of telegraph line exposed to the high-tension line a low-resistance choke coil is included in the telegraph circuit, and on the line side of each choke coil a condenser path to ground is presented to the induced currents. This arrangement is quite effective where the disturbance is not great, and where ground potentials have a low value and have a constant polarity.

Figure 379 shows a method of screening the Morse relay at a way office on a single circuit, wherein an alternative path is presented to the induced alternating currents, enabling them to pass through the station with minimum effect upon the relay.

Figure 380 shows an excellent terminal or way-office arrangement for use

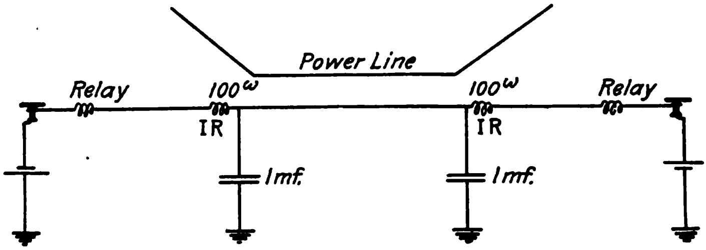


FIG. 378.—Telegraph circuit in close proximity to high-tension power line.

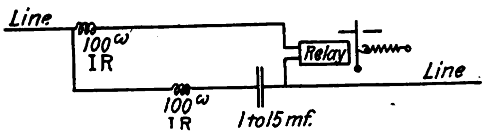


FIG. 379.—Method of screening way office relay on a single line.

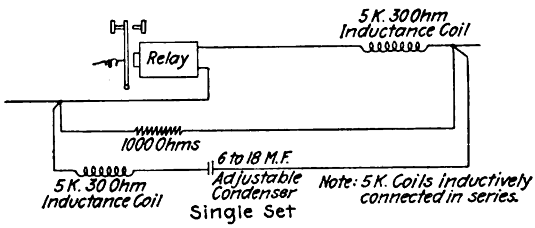


FIG. 380.—Terminal office or way office relay on a single line protected against induction from neighboring high-tension lines.

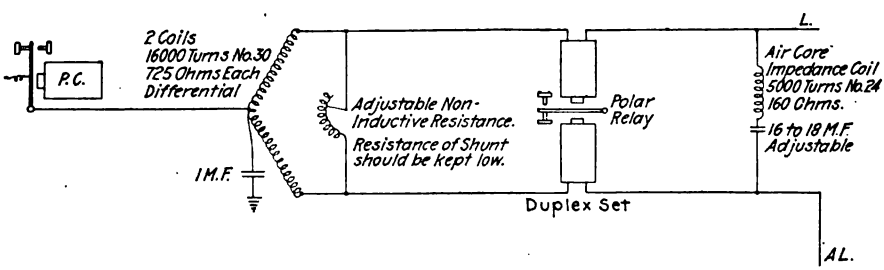


FIG. 381.—Duplexed line protected against disturbances from neighboring 25-cycle high-tension line.

on single lines, employing standard 5*K* coils for the purpose. In this arrangement the relay winding is shunted with a 1,000-ohm non-inductive resistance forming one branch of a resonant circuit which provides a path past the relay for the induced alternating currents.

Figure 381 shows the theoretical main-line connections of a differential polar duplex equipped with protective coils and condensers for off-setting the effects of induction from 25-cycle single-phase power circuits.

In balancing duplex or quadruplex sets connected into lines that are affected by heavy induction, the constant chattering of the relays when the main-line battery at both ends of the line is removed by throwing the ground switches to the left, makes it quite difficult to determine when the polar relay has been balanced magnetically.

In cases where it is important that the magnetic balance should be accurate it is necessary to place the lever of the ground switch in the center, and to open the artificial line and condenser circuits by throwing the rheostat switch and retardation resistance coil switch into the "open" position.

TRANSPOSITION OF WIRES ON POLE LINES

When two single wires of a telegraph system are joined together at terminal stations for the purpose of providing a metallic telephone circuit, it is necessary that the wires should be transposed at predetermined intervals along the line in order that there will be no "cross-talk" effects between the telephone circuit thus formed, and other telephone circuits on the same or adjacent pole lines. Transposing the two sides of the telephone circuit as above indicated also protects the telephone circuit from the effects of induction from neighboring power lines, trolley line, and telegraph circuits.

Through those sections of the line where the conductors are carried in aerial or underground cables, transposition is effected by twisting the two conductors of each metallic circuit around each other continuously, forming what are called "twisted pairs."

There are several theoretical methods of determining the number of transpositions necessary in a given distance, to protect the circuit from mutual and from foreign induction, where reasonably definite values can be determined for the various factors involved, but in practice it is found advisable not to adhere too closely to the dictates of theory in this regard, but rather to provide sufficient margin to offset any possible additions to the sources of disturbance.

Standard practice in locating the position of transposition poles is to measure a distance of 1,300 ft. from the first pole of the line and mark the pole nearest to the point so measured *A*. Then measure successive distances of 1,300 ft. each, and letter the nearest poles *B*, *C*, *B*, *A*, *B*, *C*, *B*, *A*, *B*, *C*, etc., successively, the circuits being transposed upon the poles so lettered as

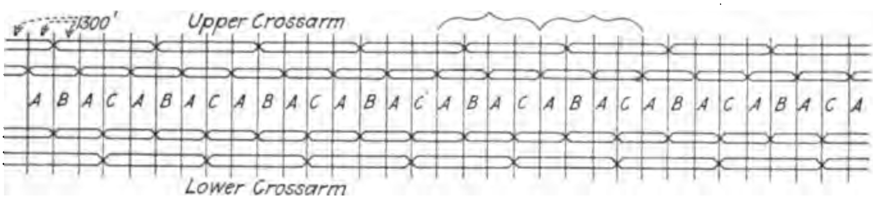


FIG. 382.—Transposition of wires. Four-pin cross-arms.

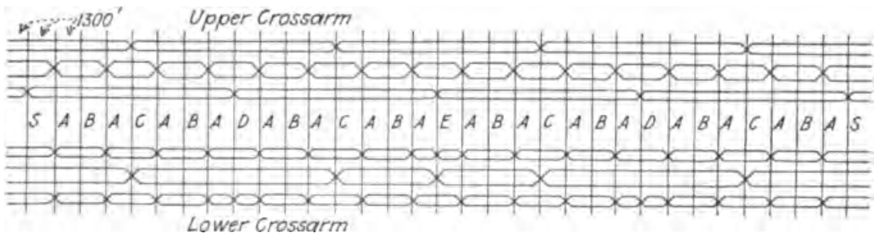


FIG. 383.—Transposition of wires. Six-pin cross-arms.

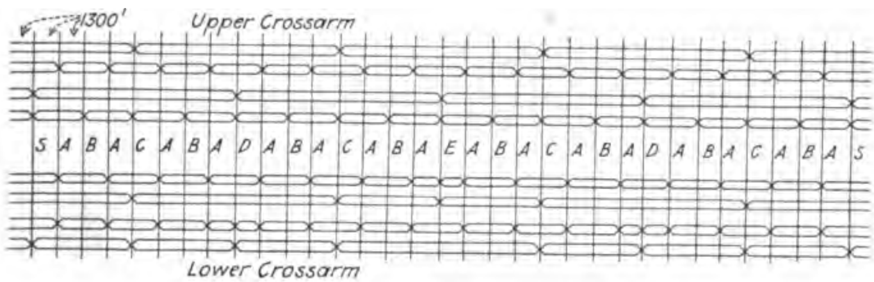


FIG. 384.—Transposition of wires. Eight-pin cross-arms.

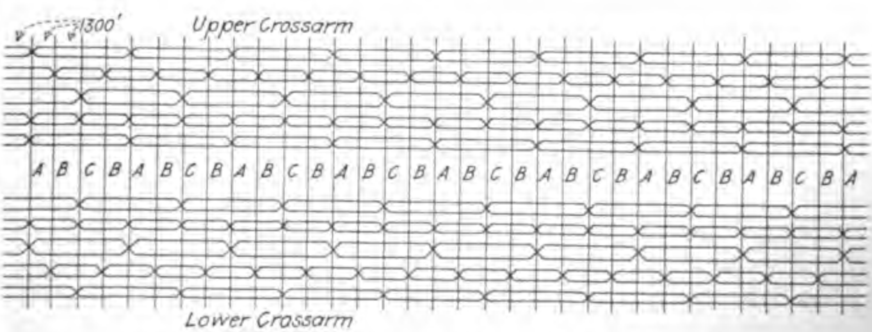


FIG. 385.—Transposition of wires. Ten-pin cross-arms.

shown in Fig. 382. The diagram shows the necessary transpositions, where two circuits are carried on the upper cross-arm and two on the lower arm.

Figures 383, 384 and 385 show respectively the scheme of transposition for six-pin, eight-pin and ten-pin arms.

All transpositions in copper circuits are made by cutting the wires on the pole side about 20 in. from the cross-arm, and slipping on each half a

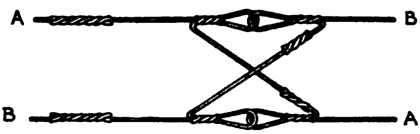


FIG. 386.—Method of transposing wires at supports.

McIntyre sleeve, with which the wires on the cross-arm side are dead-ended, one in the lower groove and one in the upper groove of the transposition glass insulator, allowing the ends to project. About 6 ft. of slack wire is then joined to the wires on the cross-arm side by using a whole McIntyre sleeve. Half sleeves are then slipped on and the wires dead-ended in the

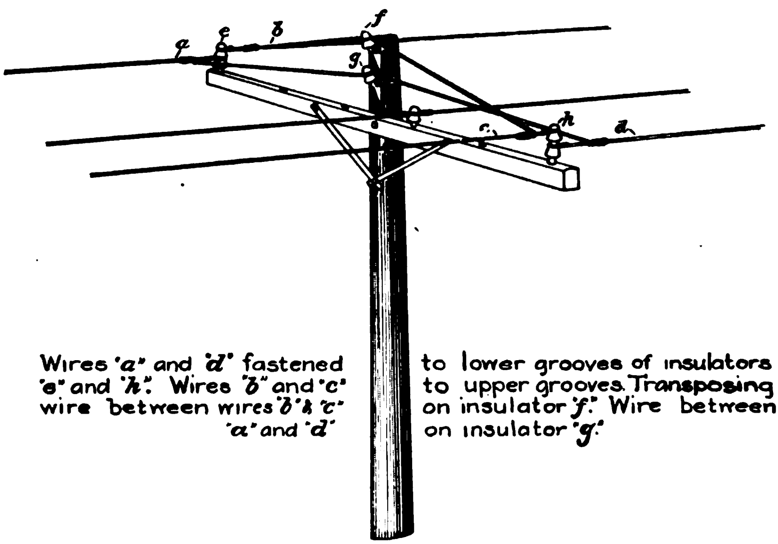


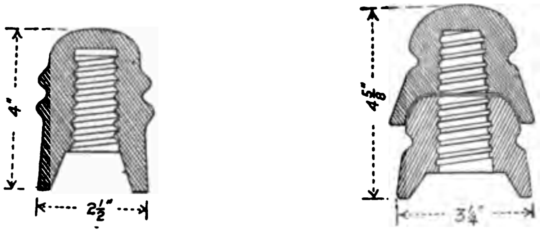
FIG. 387.—Transposition of wires, carried on end-pins.

vacant grooves of the insulators, after which the free ends are crossed and connected by half sleeves as shown in Fig. 386.

Where the wires to be transposed are located on either end of the cross-arm, transposition is effected by supporting the two cross wires upon bracket pins as shown in Fig. 387.

The transposition insulator consists of two single insulators on the same pin as shown in Fig. 388. The lower section has no top, and the pin projects through it, the upper insulator being secured on the top of the pin in the usual manner.

Figure 388 on the left shows a standard insulator, and on the right a transposition insulator.



Standard insulator | Transposition insulator.

FIG. 388.

Instead of transposing wires on the glass insulators screwed on wooden pins inserted into the tops of cross-arms in the usual manner, it is now common practice to employ iron *J* hooks driven into the cross-arm from the under side. A regulation glass insulator is screwed to the lower extremity of the *J* hook, so that the wire is carried under the cross-arm at the point of transposition.

CHAPTER XXII

TELEPHONY. SIMULTANEOUS TELEGRAPHY AND TELEPHONY OVER THE SAME WIRES

Although in long-distance telephony metallic circuits are used exclusively, it is possible under favorable conditions to use single-line grounded circuits for telephoning over comparatively short distances. This fact is noted here in view of the possibilities in the way of joining up branch-line grounded circuits to long-distance metallic circuits, which will be explained presently.

Figure 389 shows theoretically the main-line connections of a grounded-line telephone circuit, employing separate talking battery at each station. On grounded telephone lines intermediate stations may be introduced as at *A*, which shows the series connection, or as at *B*, which shows the bridging or multiple connection. At each station a 50- to 75-volt, alternating-current,

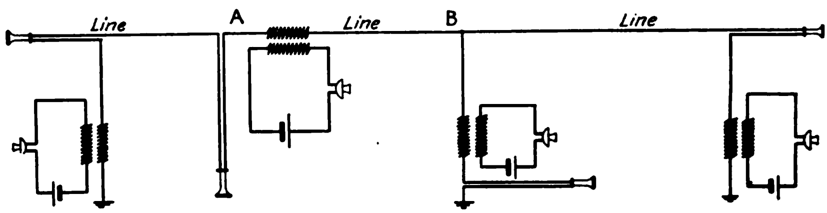


FIG. 389.—Grounded line telephone circuit.

hand-operated generator is used to operate the polarized bells at the various stations, for the purpose of signaling. As the operation of any generator connected into the line operates all of the signaling bells in circuit, each station is given a call. Where but three or four stations are located upon a line, the call for one office may be two short rings, for another three short rings, for the third four short rings, and for the fourth station, five short rings. The single short ring, generally being reserved for "ring-off" purposes. Where a larger number of offices are located upon one line, it is necessary to form combination signals in order to reduce to a minimum the number of signals required, thus, the call for one office may be two short rings, a pause, and two short rings, or, the signal "22." Likewise other offices may be given signals such as "13," "41," "21," etc.

The resistance of the ringer magnets used in grounded circuits when connected in series is about 80 ohms, and when connected in multiple, ranges from 1,000 to 2,500 ohms.

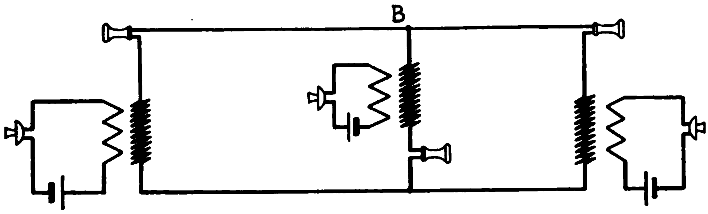


FIG. 390.—Metallic-circuit telephone line.

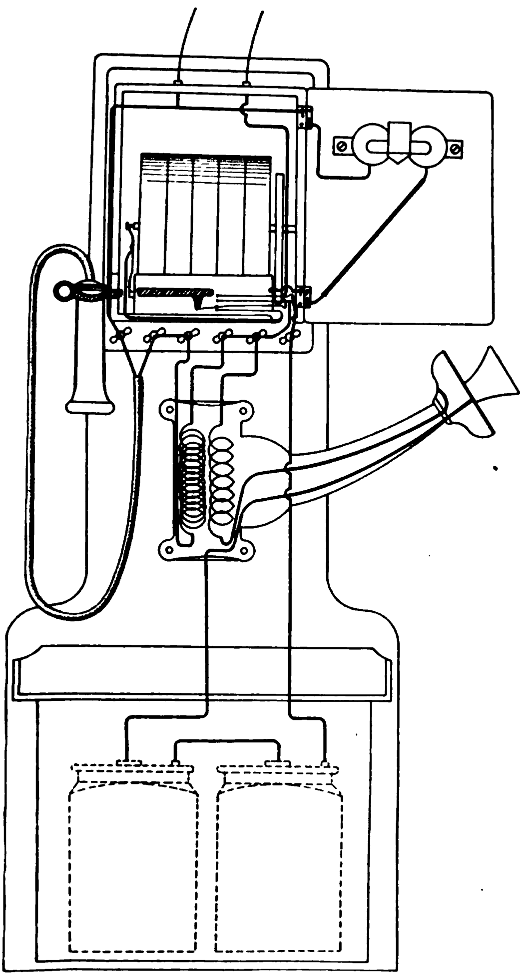


FIG. 391.—Series telephone set.

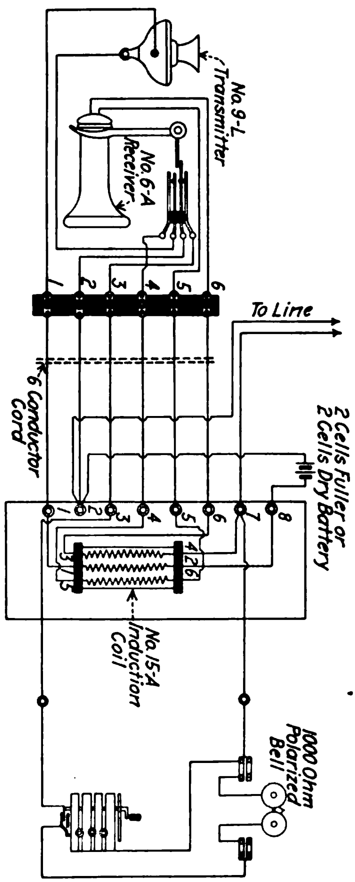


FIG. 392.—Bridging telephone set.

Figure 390 shows theoretically the main-line connections of a two-wire or metallic telephone circuit.

In the metallic arrangement it is customary to connect intermediate offices in multiple, as shown at *B*, Fig. 390, using 2,500-ohm bridging bells.

Figure 391 shows the wiring of a "series" telephone set, and Fig. 392, the wiring of a "bridging" telephone set.

The two wires used for metallic circuit telephone operation, for satisfactory working must have identical characteristics, such as resistance, capacity, leakage, and inductance. In practice slight variations are permissable in any of these factors, but the talking efficiency of the circuit is reduced if considerable variations exist. Where a sufficient number of conductors of the same gage are available it is an easy matter to effect proper balances by transposing the conductors as explained in Chapter XXI.

The current supplied to telephone transmitters may be derived from primary batteries of the Edison, gravity, Fuller, LeClanche, or dry-cell types, or from storage batteries.

CONNECTING GROUNDED LINES TO METALLIC CIRCUITS

A metallic circuit and a single grounded line may be joined together by connecting the two lines through a repeating coil *R* as indicated in Fig. 393.

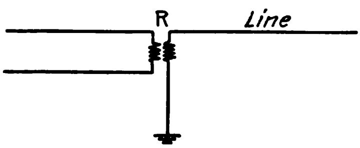


FIG. 393.—Grounded line joined to a metallic circuit through a repeating coil.

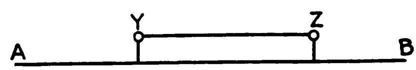


FIG. 394.—Section of a through telegraph wire serving as one side of a metallic telephone circuit.

In those cases where a single grounded telephone wire is strung upon the same pole line with a through telegraph wire it is possible for short distances to use the telegraph wire as one side of a metallic telephone circuit without seriously interfering with the operation of either circuit.

Figure 394 shows one method of accomplishing this. The telegraph wire *A–B* extends through the stations at which telephones *Y* and *Z* are located. Instead of using an earth return for the telephone circuit, a section of the telegraph wire may be used for the purpose by connecting the telephone directly to the telegraph line as indicated in the diagram. The annexed telephone circuit forms a shunt to a portion of the telegraph line, but owing to the high resistance of the telephone instruments as compared with the resistance of the section of telegraph line shunted, comparatively little of the telegraph current will be diverted. In fact, the joint resistance of the tele-

phone circuit and that portion of the telegraph conductor used will be less than that of the telegraph conductor alone, reducing to that extent the total resistance of the telegraph circuit.

A similar method of tying a telephone line to a telegraph line is shown in Fig. 395, the connection being made at each station through condensers *C* and *C′*, which permit the passage of the alternating current telephone impulses, but prevent the direct current telegraph impulses getting into the telephone apparatus.

Figure 396 illustrates still another method of utilizing a section of a through telegraph wire to form one side of a telephone circuit. At station *Y*, the junction of the two windings of retardation coil *K*, is connected with the telegraph line east, while the outside terminals of the windings of the retardation coil join the telegraph wire to the telephone wire as shown,

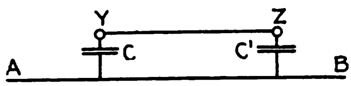


FIG. 395.—Telephone wire connected to section of through telegraph wire through a condenser.

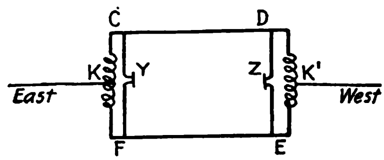


FIG. 396.—Retardation coil method of tying telephone lines to telegraph lines.

thereby forming a metallic circuit between stations *Y* and *Z* through the windings of the retardation coil at each station. At station *Z* the telegraph line west is connected to the junction of the two windings of retardation coil *K′*. For telephonic purposes, therefore, a metallic circuit is formed between stations *Y* and *Z* by way of *C–D–E–F*.

A telegraph impulse passing from east to west or *vice versa*, finds an unobstructed path through the retardation coils, due to the fact that the two windings of the coils are connected so that the inductive action of one coil neutralizes that of the other, that is, when current passes through the windings in opposite directions, as is the case when the current enters at the junction of the two windings.

While the inductive reactance of the two windings of the retardation coil to the comparatively slow telegraph impulses is neutralized, this is not the case with the high frequency telephone currents.

The impedance of the coil to the telegraph current does not much exceed its ohmic resistance, as the impedance

$\sqrt{R^2+(2\pi\ nL)^2}=R$, since the current traverses the two windings in opposite directions around a common core. Obviously where hand telegraph signals are concerned the value of n (frequency) is quite low, say, 12 or 15 per second.

The core of the retardation coil forms a continuous magnetic circuit of comparatively large physical dimensions, which tends to impede reversal of its magnetism when the high frequency alternating telephone currents tend to reverse it, and as to the telephone currents the two windings of the coil are connected in series, with each winding acting as an independent impedance coil, while the two windings are connected in series the total impedance is ascertained by the formula:

$\sqrt{(2R+2R)^2+(2\pi nL+2\pi nl)^2}=\sqrt{(R)^2+(4\pi nL)^2}$. In which the value of n may be taken as 1,000, and of L as 6 (henries).

It is evident, therefore, that the telephone currents are confined to the circuit *C–D–E–F*, while the telegraph currents will pass through the joint circuit without entering the telephones.

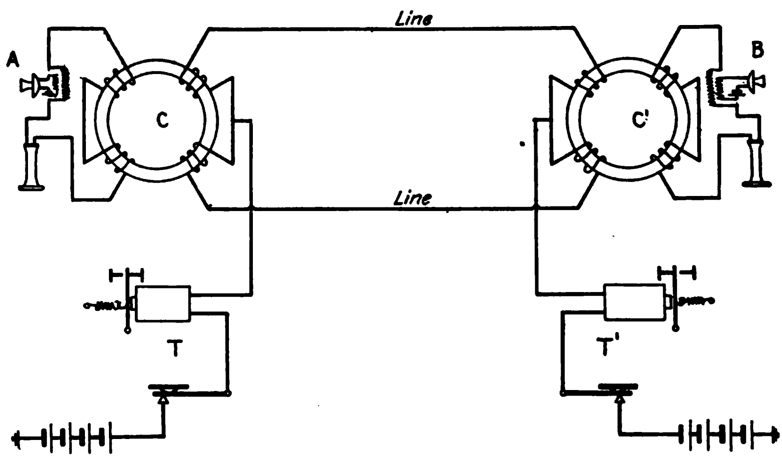


FIG. 397.—Circuits of the repeating-coil type of simplex.

Metallic circuits built up as indicated in Figs. 394, 395, and 396, should be transposed in the usual manner and for the reasons explained in the preceding chapter.

It is apparent, also, that in any of these arrangements, while intermediate telephone circuits may be inserted by bridging the telephone sets, intermediate telegraph stations cannot be introduced without seriously interfering with the operation of the telephone circuit, as in that case the telegraph impulses would be distinctly heard in the telephone receivers.

In setting up such combination circuits the material and resistance of the wire used in each side should be the same.

THE SIMPLEX CIRCUIT

The simplex circuit arranged as shown in Fig. 397, provides for telegraphing over a circuit which is at the same time being used for telephony.

There are two types of simplex apparatus, one employing a repeating coil and the other a bridged impedance, the former is illustrated diagrammatically in Fig. 397, and the latter in Fig. 398.

The repeating coil arrangement is not as efficient from a telephone transmission standpoint for long lines as the bridged impedance arrangement, as the introduction of each repeating coil of the usual type into the line has

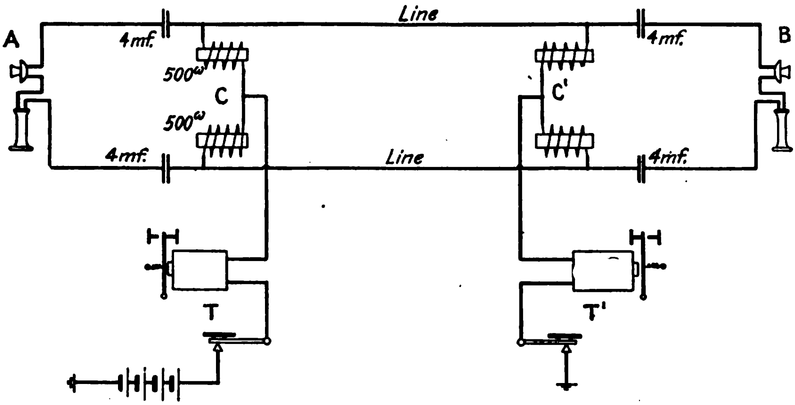


FIG. 398.—Bridged impedance coil type of simplex.

an effect equivalent to the introduction of 1 1/2 miles of No. 19 B. & S. cable conductor, or 28 1/2 miles of No. 8 B. W. G. open line. The effect of the bridged terminal equipment of the impedance coil system may be considered as equivalent to 1/4 mile of cabled conductor.

The following table of equivalents indicates the relative transmission efficiency of the various gages and kinds of wire used:

Conductor	Pounds per mile	Miles of line equivalent to 1 mile of No. 8 B. W. G.
No. 8 B. W. G., copper	435	1.0
No. 12 N. B. S. G., copper	173	0.46
No. 14 N. B. S. G., copper	102	0.28
No. 6 B. W. G., B. B., iron	573	0.19
No. 8 B. W. G., B. B., iron	378	0.16
No. 10 B. W. G., iron	250	0.14
No. 12 B. W. G., B. B., iron	165	0.11
No. 14 B. W. G., B. B., iron	96	0.08
No. 19 B. & S. cable (0.072 m.f.)	21	0.03
No. 9 B. & S. copper	210	0.54 (est.)

In Fig. 397, *A* and *B* are two telephone stations connected by a metallic circuit through repeating coils *C* and *C′*. Taps are taken from the middle of one side of each coil to telegraph sets *T* and *T′*, thence to the telegraph main-line battery and ground at each station. The two line wires carry the telephone current in opposite directions, but, acting as a joint circuit to the telegraph current, the two line wires form one side of a ground return telegraph circuit.

By noting the direction of the windings around the continuous iron core of the repeating coil, it will be apparent that the telegraph currents flow in

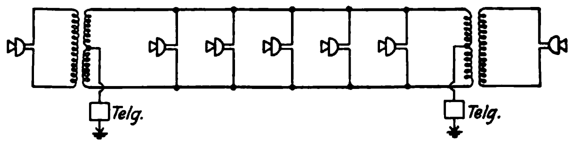


FIG. 399.—Intermediate telephone stations on simplex circuit.

opposite directions around the core, the action of one winding neutralizing the inductive effect of the other, and if the electrical characteristics of the two line wires are the same, the telegraph impulses will not affect the telephone receivers.

The retardation coil type of simplex circuit shown theoretically in Fig. 398 has two terminal telephone stations *A* and *B* connected to the two line wires forming the metallic circuit through 4-m.f. condensers. The high-frequency alternating talking current readily passes through the condensers, while the slowly pulsating direct-current Morse impulses cannot enter the

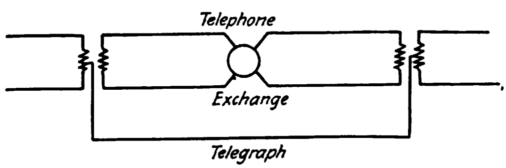


FIG. 400.—Simplex circuit connected through an intermediate telephone exchange.

condenser circuit containing the telephones. The retardation coil bridged across the line wires at each terminal station has two 500-ohm windings around an iron core, giving the coil a very high impedance to alternating currents. At the junction of the windings of the two coils the Morse circuit is tapped off, leading to relay, key, battery and ground.

Inasmuch as the resistance and reactance of the coils and of the two line wires forming each side of the circuit are identical, the current divides equally in the two branches of the circuit, and as the difference of potential at any point along the line is the same in each wire, it is evident that inter-

mediate telephone stations may be bridged across the two line wires. See Fig. 399.

In those cases where the line is run through an intermediate telephone exchange, repeating coils are connected into the metallic circuit on each

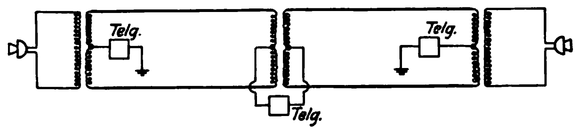


FIG. 401.—Intermediate telegraph station connected into a simplex circuit.

side of the exchange switchboard as indicated in Fig. 400, the telegraph circuit being completed through the exchange by means of a wire connecting the middle point of each retardation coil as shown.

Figure 401 shows a simplex circuit with an intermediate telegraph station.

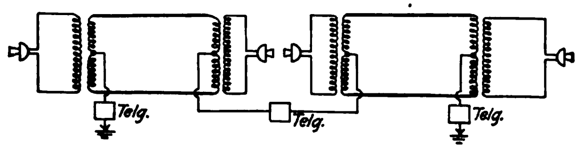


FIG. 402.—Intermediate telephone and intermediate telegraph station connected into a simplex circuit.

Figure 402 shows a simplex circuit with an intermediate telephone station and an intermediate telegraph station inserted.

PHANTOM TELEPHONE CIRCUITS

The phantom is an arrangement by which three telephone circuits may be obtained from two pairs of line wires. The combination is referred to as consisting of two physical circuits and one phantom circuit.

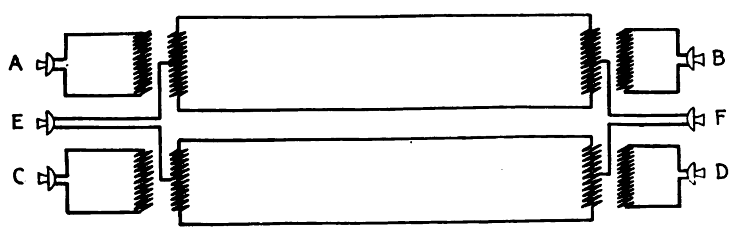


FIG. 403.—Phantom telephone circuit.

A and *B*, Fig. 403, are two stations connected by a metallic circuit, as also are stations *C* and *D*. A repeating coil is inserted at each end of each metallic circuit as shown in the diagram. At each station the two line wires

from a third telephone set are connected to the middle of each repeating coil, thereby employing the two wires of each metallic circuit as one side of an additional, or phantom circuit.

Special forms of transposition of the four wires are required in order to prevent cross-talk. Fig. 404 shows various transposition arrangements

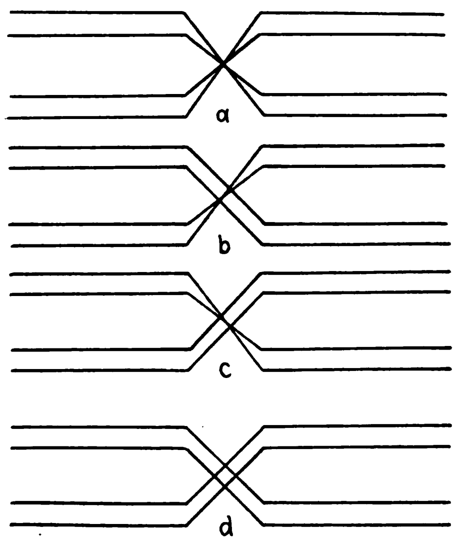


FIG. 404.—Special forms of line transposition necessary where phantom circuits are made up.

of the wires of the physical circuits and of the two sides of the phantom circuit.

Intermediate stations may be inserted in each physical circuit, and there will be no interference; provided a correct balance is maintained between the two wires forming the circuit.

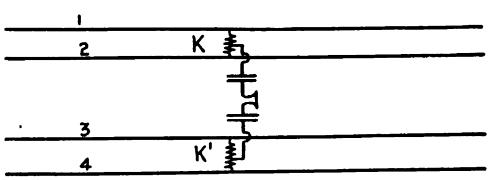


FIG. 405.—Intermediate telephone station on phantom circuit.

Figure 405 shows the necessary connections for inserting an intermediate station into the phantom circuit. Retardation coils K and K' are bridged across the physical circuits. From the center of each of these coils a tap is taken to one side of a condenser, the other terminal of which is

connected with the telephone set to be bridged into the phantom circuit. The presence of the retardation coil in the physical circuit does not appreciably interfere with the talking efficiency of that circuit as the inductive resistance of the coil to high-frequency currents tending to enter it at one end and leave at the other acts to prevent the currents circulating in the physical circuit from being shunted. The phantom currents, on the other hand, traveling in the same direction in wires 1 and 2, and 3 and 4, enter the retardation coils at both ends at the same instant—the only opposition presented to the incoming currents being that of non-inductive resistance. The out-going currents from the intermediate phantom station pass through the windings of the retardation coils in opposite directions, again encountering only non-inductive resistance.

THE PHANTOM SIMPLEX CIRCUIT

In combining circuits to provide phantom simplex operation, there is a certain degree of loss in the efficiency of telephone transmission, and the satisfactory operation of the system requires that in every case the wires em-

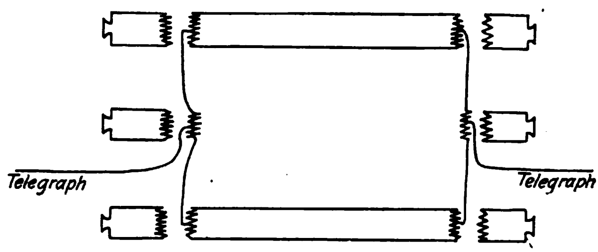


FIG. 406.—Phantom simplex circuit.

ployed in forming the different sides of the circuit must be of the same composition and of the same resistance.

Figure 406 illustrates theoretically the manner in which a telegraph circuit is superimposed upon a phantom circuit already serving as two telephone circuits. Intermediate telephone stations may be connected into either physical circuit or into the phantom circuit without causing interference. In the case of the phantom intermediate connection it is necessary to use condensers as indicated in Fig. 405.

It will be apparent that when one side of a telegraph circuit consists of four line wires, as in the phantom simplex arrangement, the resistance of the circuit thus made up will be comparatively low and (as is also the case with the ordinary simplex arrangement) the telegraph circuit being grounded at each terminal station, some difficulty is likely to be experienced due to earth currents. The remedy is to insert artificial non-inductive resistance at one or both of the telegraph stations.

In arranging phantom circuits, cabled conductors should be avoided as

far as possible, although if "double-twisted" pairs are used, reasonably efficient operation is possible.

THE COMPOSITE CIRCUIT

In arranging for composite operation it is well to remember that iron wire is much inferior to copper wire of the same size when used for telephone purposes, and also that cabled conductors are much less efficient than open conductors suspended on poles in the usual manner. Where the employment of cabled conductors is unavoidable, from a transmission standpoint paper-insulated conductors are considerably more efficient than rubber-insulated wires; that is, for wires of the same size. This is owing to the relatively high electrostatic capacity of rubber-insulated conductors.

In view of the widely different conditions encountered it is difficult to lay down definite rules applicable to all proposed installations of composite apparatus, so far as the length of line and possible number of stations in circuit are concerned.

Except in those cases where composite service has been contemplated in the original construction of the line and stringing of the wires, each particular telegraph line or telephone line must be considered separately before a correct determination can be made in regard to its adaptability for composite service.

THE GROUNDED LINE COMPOSITE

Figure 407 shows the circuits of a grounded composite installation at a terminal office and at an intermediate telegraph office. The direct-current

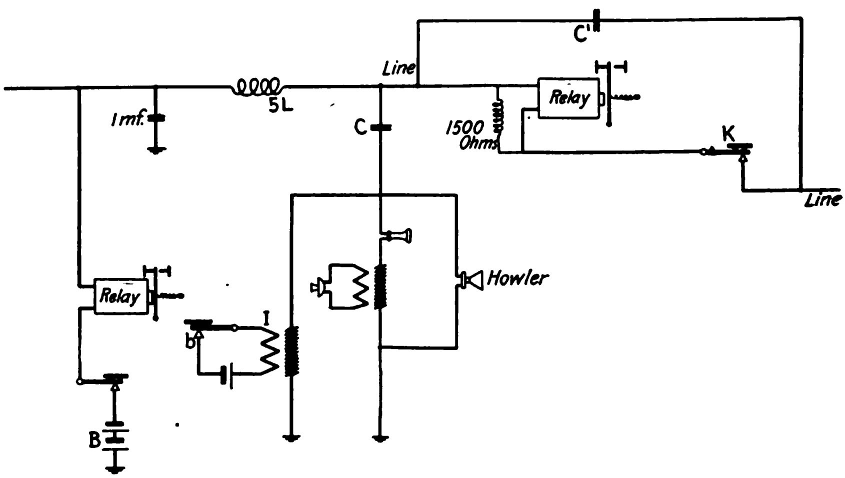


FIG. 407.—The grounded composite.

impulses from the telegraph battery *B* have an uninterrupted path via the key and relay at the terminal station, through the retardation coil 5–*L*, over

the line wire, through the Morse relay at the intermediate station, and on to the distant terminal station, in the same manner passing through any other intermediate telegraph offices inserted between the two terminal stations.

The presence of the condenser C, prevents the telegraph impulses from being shunted to earth through the telephone apparatus, while the presence of the condenser C' connected around the Morse relay at the intermediate telegraph station provides a path for the high-frequency alternating telephone currents past that station, whether the Morse key K is open or closed.

THE HOWLER SIGNAL

In operating call-bell signals over the simplex circuit (Fig. 398) the alternating currents produced by the generator pass over the line in the same manner as the talking currents, and, ordinarily no difficulty is experienced provided high power generators and condensers having a large enough capacity are used in connection therewith. In many modern telephone exchanges one side of the ringing generator is grounded. Obviously such an arrangement cannot be used for signaling over simplex circuits without causing chattering of the armatures of the Morse relays while the signaling impulses are being sent over the line. It is necessary, therefore, where the retardation coil type of simplex is used to provide a metallic generator circuit.

FIG. 408.—The howler.

In the repeating coil type of simplex the grounded generator may be employed, as the two windings of the coil have no direct electrical connection with each other.

In signaling over composited lines, a "howler," Fig. 408, is generally used.

This instrument consists of a special form of telephone receiver equipped with a resonating megaphone. The diaphragm is operated by the high-frequency signaling currents produced by an induction coil fitted with an interrupter, as at I, Fig. 407—depressing the button b closes the primary circuit of the induction coil connected with a source of direct current, causing the vibrator to act, resulting in sending out powerful high-frequency signaling currents over the line to actuate the howler connected into the distant telephone set.

The sound emitted by the howler may be varied by adjusting the position of the diaphragm relatively to the electromagnets.

THE METALLIC CIRCUIT COMPOSITE

In all cases where it is desired to maintain telephone service over long distances, say from 100 to 1,000 miles, the metallic circuit is indispensable.

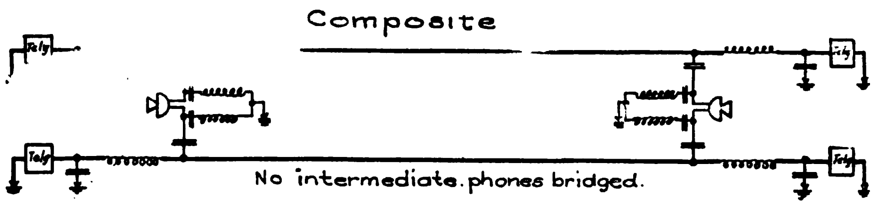


FIG. 409.

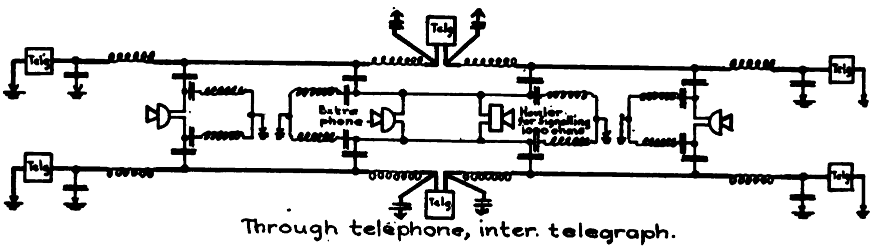


FIG. 410.

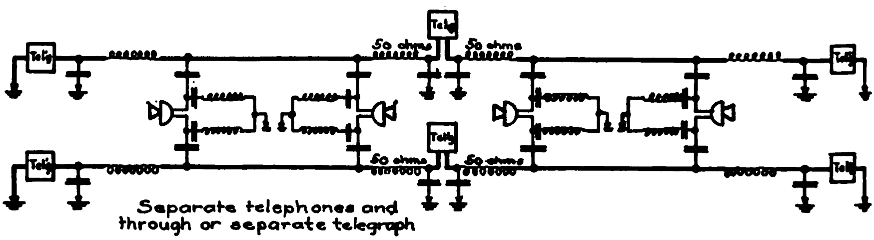
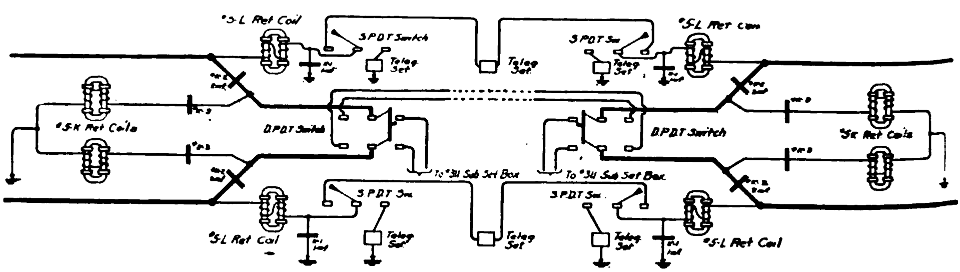


FIG. 411.



INTERMEDIATE COMPOSITE.
(THEORY)

FIG. 412.

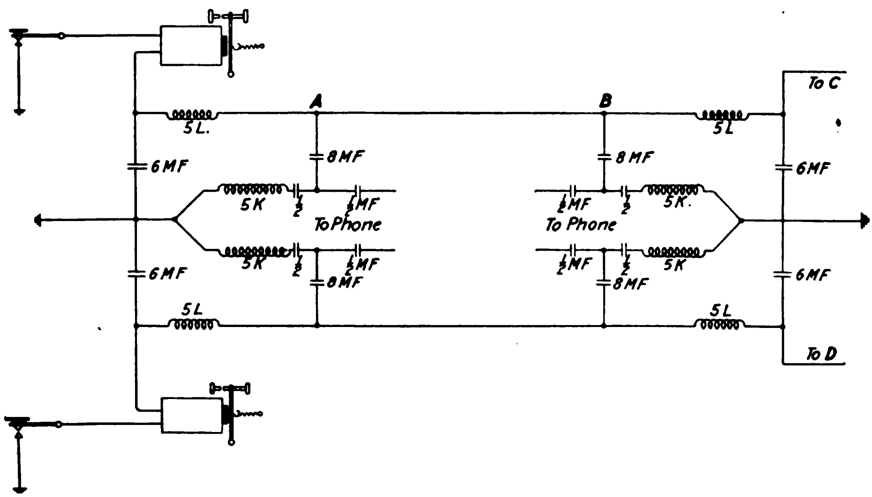


FIG. 413.—Complete connections of the composite circuit, showing condenser capacities.

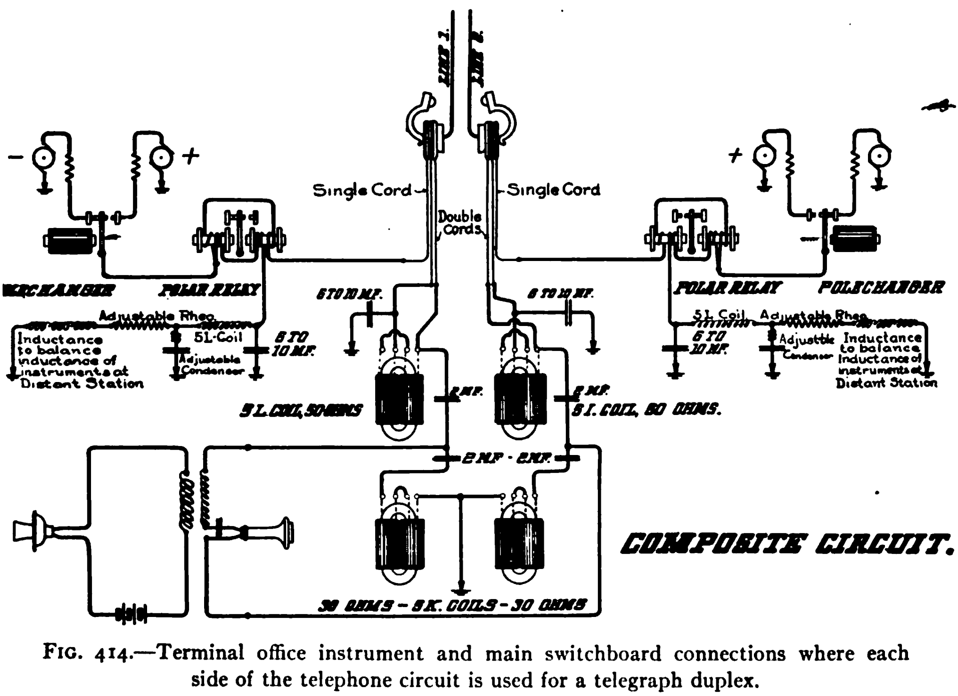


FIG. 414.—Terminal office instrument and main switchboard connections where each side of the telephone circuit is used for a telegraph duplex.

The organized apparatus of the metallic circuit composite makes possible the employment of each side of the telephone circuit as a telegraph circuit.

Figure 409 shows the schematic circuit arrangements of a composited line employing the two line wires as a metallic telephone circuit, and each line wire as a separate grounded telegraph circuit.

Figure 410 shows the theoretical arrangement of circuits, where the two line wires are used for through telephone service and where each line wire is used for telegraph service between two terminal stations including an intermediate telegraph station on each line.

Figure 411 shows a similar arrangement, providing for separate telephone circuits in both directions from an intermediate office, and for either through

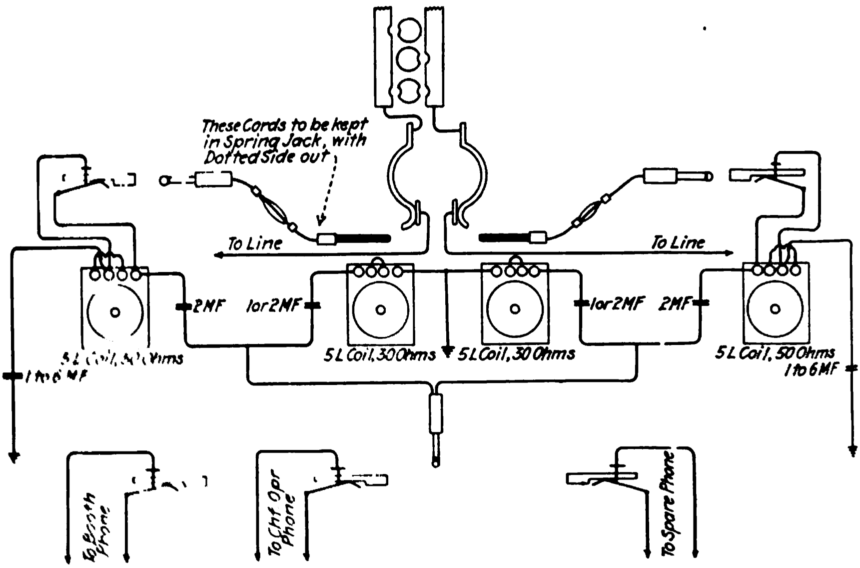


FIG. 415. Instrument binding-post connections at a terminal office. Composite circuit.

or separate telegraph service. Fig. 412 shows the switching arrangements at the intermediate office which provide for cutting any of the circuits, and for connecting them for through service between terminal stations.

Figure 413 shows with fewer lines the actual arrangement of circuits at the intermediate office. Telephone service is maintained between stations A and B, while telegraph service is maintained over one wire between station A and a distant station C, and over the other wire between station A and a distant station D. In this diagram the condenser values found necessary in a particular case are noted.

Figure 414 shows the required instrument and main switchboard con-

nections where duplex telegraph service is maintained over each of the two wires used in forming the metallic telephone circuit.

Figure 415 shows the actual binding-post connections of the retardation coils, condensers, and telephone pin-jacks. The apparatus is connected to the two line wires by means of the cords bearing on one end double plugs and on the other double wedges, the plugs being inserted in the pin-jacks, and the wedges in the spring-jacks of the main-line switchboard as indicated in the diagram.

REPEATING COILS AND RETARDATION COILS USED IN SIMPLEX AND COMPOSITE CIRCUITS

Figure 416 shows a view of the form of repeating coil known as 37–*A*. These coils have two primary windings of 35 ohms each and two secondary windings of 35 ohms each. The coils are used in phantom toll circuits and

FIG. 416.—37-A repeating coil.

in simplex circuits. The size of the baseboard upon which the coil is mounted is 11 in. × 8 5/8 in. Fig. 417 shows the terminal markings and circuit connections of the 37–*A* type coil when used for simplex working.

Figure 418 shows the terminal connections of the 5–*N* type retardation coil. This coil has four windings of 250 ohms each. Total resistance 1,000 ohms when measured with direct current. The inductance of the coil with windings in series is 507 henries, and with the windings in multiple 3.1 henries.

The 5–*K* type retardation coil has two windings of 15 ohms each. Total resistance measured with direct current 30 ohms. The effective resistance of the coil to alternating currents having a frequency of 1,000 p.p.s. is 3,000 ohms with the windings in series inductively. The inductance with both windings in series inductively is 3.1 henries.

The 5–*L* type retardation coil has two windings of 25 ohms each. Total resistance measured with direct current is 50 ohms. The effective resistance measured with alternating current of 1,000 p.p.s. is 2,500 ohms with both windings in series inductively. With both windings in series opposing each

other, the effective resistance is 700 ohms. The inductance of the coil with both windings in series inductively and measured with alternating current having a frequency of 1,000 p.p.s. is 4.8 henries, and under the same conditions of current with both windings in series opposing inductively 3 henries.

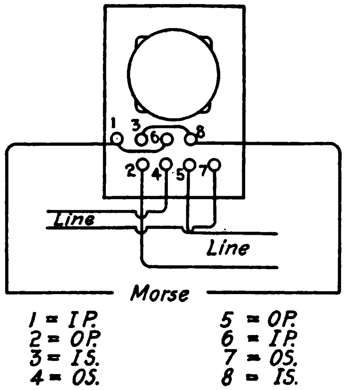


FIG. 417.—Terminal markings and connections of the 37-A coil.

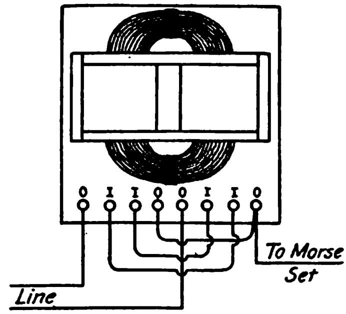


FIG. 418.—Terminal markings and connections of 5-N type retardation coil.

The 5-*U* type coil (which is of the same construction as the 37-*A* type of coil) used in connection with the Western Union standard quadruplex has two windings of 500 ohms each. Total resistance 1,000 ohms measured with direct current. The inductance with both windings in series is 584 henries and with the windings in multiple 3.84 henries.

CHAPTER XXIII

SPECIFICATIONS FOR COPPER AND IRON WIRE, AERIAL, UNDERGROUND, SUBMARINE, AND OFFICE CABLES

SPECIFICATION FOR HARD-DRAWN COPPER WIRE

Rolling and Drawing

The copper bars, before rolling, shall be free from defects, and each coil shall be in one continuous length without joints.

All wire furnished under this specification shall be perfectly cylindrical, uniform in size and quality, free from flaws, splits, kinks and other defects. The manufacturer shall cut off before inspection sufficient length from each end of every coil to insure freedom from defects.

MECHANICAL AND ELECTRICAL REQUIREMENTS

B. & S. gage	Diameter mils average must not exceed	Weight per mile pounds			Breaking weight pounds		Minimum percentage elongation allowed in 5 feet	Maximum mileohm allowed at 60° F.
		Maximum allowed	Minimum allowed	Average must not exceed	Minimum allowed	Lot must average at least		
7	144	337	328	332.5	1,020	1,050	1.09	
7½	137	305	296	300.5	930	950	1.07	
8	128.5	268	260	264	820	840	1.06	
9	114	212	204	208	650	670	1.02	894.7
9½	104	176	169	172.5	540	555	1.00	
10	102	169	163	166	520	535	1.00	
B. W. G.								
8	165	439	431	435	1,328	1,378	1.14	

Testing and Apparatus

The mechanical and electrical tests shall be made in a manner and with apparatus approved by the electrical engineer of the telegraph company.

Tests are to be applied to sample pieces of wire, cut from not less than one-tenth of the number of bundles, as selected by the inspector of the telegraph company from the whole lot of wire under inspection.

Samples selected at random by the inspector shall be used for electrical measurement.

Rejections

The inspector may reject any wire which does not meet the foregoing mechanical and electrical requirements; and, if such rejections include the entire lot, the expenses of inspection shall be borne by the manufacturer.

Any imperfect material or work discovered before acceptance of the wire shall be replaced or corrected upon demand of the telegraph company, even if such imperfections were not apparent during inspection of the samples selected.

Coils

Each coil to be a continuous length without joint or splice, and to have an inside diameter of from 20 to 22 in.

Under direction of the inspector, a lead seal of the telegraph company shall be attached to the *inside* of each accepted coil with a soft copper wire fastener. Such lead seals and wire fasteners will be provided by the telegraph company. All other attachments to be made with strong twine.

Weight of Coils.—The length and weight of wire in each coil of the same gage to be as nearly equal as practicable, and the weight to be determined by the following:

Ninety-five per cent. of the bundles of gage No. 9 B. & S. (.114 in.) or smaller, to weigh not more than 220 lb., nor less than 190 lb. each. Five per cent. of low-weight coils will be accepted, the minimum weight to be 125 lb.

Ninety-five per cent: of the bundles of gages larger than No. 9 B. & S. to weigh not more than 220 lb., nor less than 150 lb. each. Five per cent. of low-weight coils will be accepted, the minimum weight to be 125 lb.

Each coil shall be securely bound with at least four separate wrappings of strong twine, and shall afterward be so protected by wrappings of burlap that there will be no danger of mechanical injury in transportation. Each coil shall have the weight, gage and length of wire plainly and indelibly marked on two strong tags, one of which shall be attached to the coil inside of the burlap, and the other outside of the burlap. Upon the inside tag shall be marked the order number of the telegraph company and the date of inspection.

SPECIFICATION FOR GALVANIZED IRON WIRE

All wire furnished under this specification shall be perfectly cylindrical, uniform in size and quality, free from flaws, splits, kinks and other defects. The manufacturer shall cut off before inspection sufficient length from each end of every coil to ensure freedom from all such defects.

Testing Apparatus.—The mechanical and electrical tests shall be made in a manner and by apparatus approved by the electrical engineer of the telegraph company.

The wire must meet the requirements of the following table.

TABLE OF MECHANICAL AND ELECTRICAL REQUIREMENTS

Birmingham gage	Diameter mils	Weight per mile pounds	Breaking weight pounds		Twists in 6 in.		Percentage elongation	Maximum mile ohm allowed at 60° F.
			Lot must average at least	Minimum allowed	Lot must average at least	Minimum allowed		
No.								
4	238	787	2,200	2,120	15	12	15	4,700
5	220	673	1,880	1,820	16	13	15	
6	203	573	1,600	1,550	18	15	15	
7	180	450	1,260	1,210	20	17	14	
8	165	378	1,060	1,020	22	18	13	
9	148	305	860	820	25	21	12	
10	134	250	700	670	25	21	12	

Tests are to be applied to sample pieces of wire cut from not less than one-tenth of the number of bundles as selected by the inspector of the telegraph company from the whole lot of wire under inspection.

The twist tests to be made by properly gripping the sample wire at the ends by two vises whose jaws are 6 in. apart at the gripping points, and causing one vise to revolve at right angles to the wire at a uniform speed of about one revolution per second. The twists to be reckoned by the number of complete revolutions made by the revolving vise before the wire breaks.

Test pieces taken at random, shall be used for electrical measurement, and the resistance calculated to 60° F. in international ohms, using a temperature coefficient, for iron of 0.0029 ohm per degree. The electrical resistance of the wire in ohms per mile at a temperature of 60° F. must not exceed the quotient obtained by dividing the constant number 4,700 by the weight of the wire in pounds per mile. The inspector may measure the electrical resistance of as many samples as he desires to test.

If upon test it be found by the inspector that the requirements for the electrical or mechanical properties of the wire, or for the finish, are not fulfilled when the wire is offered for acceptance, the expense of all tests made by said inspector on such defective wire shall be borne by the manufacturer.

Galvanizing

All wire must be thoroughly galvanized. Samples of the wire under inspection shall be dipped into a solution of sulphate of copper, saturated at 60° F. and allowed to remain for one minute, when they are to be withdrawn, washed and wiped clean. The galvanizing shall admit of the process four times without any signs of a reddish deposit upon the wire.

Samples shall bear coiling around a cylindrical bar, twelve times the diameter of the sample without any signs of the zinc flaking or peeling off.

Coils

Each coil shall be of a continuous length and must not contain more than one splice which must be well soldered.

The inside diameter of the coil to be from 20 to 22 in.

Under direction of the inspector, a lead seal of the telegraph company shall be attached to the inside of each accepted coil with a wire fastener. Such lead seals and wire fasteners to be provided by the telegraph company.

Weight of Coils

The length of wire in each coil of the same gage to be as nearly equal as practicable, and to be determined by the following:

No. 4 B. W. G. shall contain 4 coils per mile.
No. 5 B. W. G. shall contain 3 coils per mile.
No. 6 B. W. G. shall contain 3 coils per mile.
No. 7 B. W. G. shall contain 2 coils per mile.
No. 8 B. W. G. shall contain 2 coils per mile.
No. 9 B. W. G. shall contain 2 coils per mile.
No. 10 B. W. G. shall contain 1 coil per mile.

Each coil shall be securely bound with four strong binding wires, the joints of these binding wires to be inside the coil. Each coil shall have its weight plainly and indelibly marked on a strong tag which shall be firmly attached to the inside of the coil.

SPECIFICATIONS FOR STRANDED GALVANIZED STEEL WIRE

Gage B.W.G.	Diameter wire	Diameter strand	Lay in inches	Breaking weight	Maximum elongation 24 in.	Minimum elongation 24 in.	Pounds per 100 ft.
8	0.165	$\frac{1}{2}$	$4\frac{3}{4}$	11,000	20	11	52
12	0.109	$\frac{5}{16}$	$3\frac{1}{2}$	4,860	18	11	22
14	0.083	$\frac{1}{4}$	3	3,050	17	9	13
16	0.065	$\frac{3}{16}$	2	2,000	15	9	8

Initial Strain

No piece of wire under test shall be subjected to more than 10 per cent. of its required breaking weight before its elongation is considered.

Galvanizing

Each wire must be thoroughly galvanized. Samples of the wire under inspection shall be dipped into a solution of sulphate of copper, saturated at 60° F. and allowed to remain for one minute, when they are to be withdrawn, washed and wiped clean. The galvanizing shall admit of this process four times without any signs of a reddish deposit upon the wire. Samples must bear coiling around a cylindrical bar twelve times the diameter of the sample, without any signs of the zinc flaking or peeling off.

SPECIFICATION FOR AERIAL TWISTED PAIR (RUBBER COMPOUND DIELECTRIC) CABLE

All conductors to be of No. 14 B. & S. (64 mils diameter) thoroughly annealed copper, 98 per cent. pure, according to Matthiessen's standard, equal in strength, finish, and pliability to the best market grade, well tinned and uniformly coated to a diameter of 158 mils with a high-grade rubber permanent insulating compound, which shall adhere closely to the wire, and which shall not deteriorate under ordinary conditions.

Each insulated conductor, before being laid up into cable form, must have its dielectric subjected in water, after 24 hours immersion, to a strain of not less than 1,000 volts alternating current between the conductor and the water, applied for one minute from a suitable generator or transformer; and must show while in the tank, after such immersion, an insulation of not less than 300 megohms per mile at 60° F., with not less than 100 volts applied for one minute. Test to be made by standard testing instruments in the presence of an inspector of the telegraph company.

All conductors for test, either in coils or reels, must have tags securely attached, giving in plain figures the coil or reel numbers, the number of feet in each coil or reel, the gage of wire, and diameter of insulation; and such coils must so far as practicable be in uniform lengths corresponding to the length of the cable.

Each insulated conductor in the cable must be protected by a closely woven cotton braid of not less than 15 mils thickness, thoroughly saturated with a compound which is not soluble in water, which does not act injuriously upon the permanent insulating compound, braid or tape, and which is not objectionable to handle.

The two wires of a pair shall be twisted together, the length of the lay not to exceed 6 in.

One condcutor of each pair and one pair in each layer to be corded for tracing.

The wires in each length shall be each of one piece and free from joints.

The twisted pairs shall be laid up into a cylindrical core with the layers in reverse directions.

Each pair of wires to be laid up with cushioning strands of saturated jute yarn of proper size.

The cable must be wrapped over all with flexible cotton tape of first-class quality, saturated with first-class weatherproof compound. The tape must not be less than 20 mils thick, must have a lap of one-half its width, and firm adherence where lapped, so that it will not readily come apart. Over this the cable must have a durable protection of circular loom, braid, or tape, covering acceptable to the telegraph company, thoroughly saturated with the aforesaid compound.

The finished cable must not be sticky or objectionable to handle.

All cable made up as above, prior to shipment from factory, and after being placed upon reels, must have each length again tested for insulation by the inspector of the telegraph company; and each conductor under test must show an insulation (when all of the other conductors of the length are grounded) of not less than 500 megohms per mile at 60° F., with not less than 100 volts applied for one minute in the usual manner.[1] The conductors of the completed cable must also be tested for continuity, and the inspector shall make such tests for capacity and conductivity as he thinks advisable.

The contractor will be required to furnish a table of coefficients of the resistance of the dielectric, showing its decrease above and its increase below 60° F., within the limits of variation of temperature to which the cable may be subjected during test.

The reels upon which the cable is shipped must be strong and well protected, and the cable neatly wound thereon with both ends so arranged that tests of the conductors on the reels may readily be made.

A tag must be securely fastened to each reel, upon which the contractor must record the exact number of feet from end to end of the cable upon the reel, the number of conductors in the cable, and the date of shipment to the telegraph company from the contractor's factory.

The contractor must give the usual guarantee that the cable will remain in good condition for one year after delivery, provided it is not used for currents of over one ampere, or having an electromotive force of over 500 volts; and must agree to repair or to reimburse the company for any expenditures incurred in repairing defects that may appear during that period, not caused by mechanical or other extraneous injury.

The cable must conform in quality and manufacture to a sample previously approved by the telegraph company.

[1] Omitting immersion.

SPECIFICATION FOR LEAD COVERED AERIAL OR UNDERGROUND SATURATED PAPER CABLE

Conductors

Each conductor to be No. 14 B. & S. gage (0.064 in.) soft-drawn copper wire, in one piece and free from joints.

Insulation

Each conductor to be insulated with three wrappings of the best grade manila paper to a diameter of 158 mils.

The whole core to be served with not less than three thicknesses of the best grade manila paper to a total thickness equal to that on the conductors and comprising not less than two wrappings. All wrappings to be thoroughly saturated with a high-grade insulating compound.

Layers and Marking

The conductors to be properly laid up with a marking wire in each layer.

Sheath

Sheath to be not less than one-eighth inch thick and to contain 3 per cent. of tin by weight, to be uniform in composition and thickness and free from holes, splices, joints, porous places, or other defects, and to fit so closely as to leave no space between the core and the lead.

Electrical Tests

The finished cable shall be immersed in a tank of water for 24 hours, at the end of which time the dielectric of each conductor shall be subjected to a strain of not less than 2,000 volts alternating current applied for one minute from a suitable generator or transformer. The insulation of each wire shall then be tested against all other wires and the sheath of the cable and must show a minimum insulation of 200 megohms per mile at 60° F, with 100 volts applied for one minute. Each conductor of the *finished cable* shall have a resistance of not more than 14.5 ohms per mile at a temperature of 68° F.

The above tests to be made by an authorized inspector of the telegraph company in the presence of the manufacturer's representative.

The Company requires the manufacturer to furnish a reliable table of coefficients of the dielectric's resistance, showing its decrease above and increase below 60° F., within the limits of variations of temperature to which

the cable may be subjected during tests, and the minimum of 200 megohms per mile will be modified accordingly.

One conductor in each layer, as a tracer, to be well tinned, wrapped with dark blue paper and wound spirally with medium weight black cotton thread.

Reels

The finished cable to be free from mechanical defects and to be furnished in lengths as specified and wound on reels of suitable diameter. These reels are to have iron bushings of sufficient strength to safely carry the cable, and the cable to be wound thereon with both the inner and outer ends so arranged as to enable electrical tests to be made of the conductors while on the reel. A tag shall be securely attached to the reel, upon which shall be recorded the manufacturer's name, the exact number of feet of cable upon the reel, the number of conductors in said cable, and the date of shipment to the telegraph company from the factory.

Immediately after the cable has been tested and inspected by the telegraph company's inspector, the ends of the cable shall be sealed with solder, and the inner end properly protected to prevent mechanical injury while in transit.

When the manufacturer is required to draw the cable into a subway, it is to be installed with the proper splices free from all mechanical injury. Within thirty days after being laid, the cable shall be tested as herin described by an authorized inspector of the telegraph company and must show the insulation herein required.

If the diameter of the cable called for in this specification is too great to admit of its being pulled into the duct of the subway provided, the Company is to be notified prior to the manufacture of the cable.

Manufacturer's Guarantee

The manufacturer to guarantee the perfection of the cable and that the cable will remain in good working condition during a telegraph or telephone service of one year after it is delivered. During the first year after the cable is purchased the manufacturer to repair any defects due to faulty materials or manufacture, or to reimburse the company for expenditures incurred in repairing such defects. The manufacturer not to be responsible for defects caused by mechanical injury.

SPECIFICATION FOR LEAD-COVERED TWISTED-PAIR PAPER SUBMARINE CABLE

Conductors

Conductors to be of gage as ordered, of soft-drawn copper wire, preferably in one piece, free from joints; when joints are made they must be so brazed that there will be no reduction in the tensile strength of the wire.

Insulation

Each conductor shall be insulated with not less than three spiral wrappings of the best grade manila paper, so that the total thickness of the insulating wall will be between 46 and 48 mils.

Twists of Pairs and Marking

The two wires of a pair shall be twisted together, the length of the lay not to exceed 6 in. The conductors of each pair to be—one red and one white, and one white conductor in each layer to be spirally wound with coarse black thread for a layer tracer.

Core

The twisted pairs shall be laid up into a cylindrical core with the layers in reverse directions. The whole core to be served with not less than three thicknesses of the best grade manila paper to a total wall thickness equal to that on the conductors and comprising not less than two wrappings.

The cable must be laid up very compactly. For this reason the paper insulation should be applied loosely so that when the pairs are tightly cabled together, the interstices between the conductors shall be filled with dense paper. In the event of the number of pairs called for not permitting the construction of a compact core, the number of pairs may be exceeded by the amount necessary to insure such construction.

Sheath

The lead covering must be of uniform composition and thickness, containing 3 per cent. of tin by weight, and free from holes, splices, joints, porous places or other defects; and shall fit so tightly as to make the core compact.

The thickness shall be in accordance with the following sizes of armor wire:

For No. 4 B. W. G., sheath to be 3/16 in. thick.
For No. 6 B. W. G., sheath to be 1/8 in. thick.
For No. 8 B. W. G., sheath to be 1/8 in. thick.

Jute Covering over Sheath

The lead sheath shall be covered with three layers of jute, tightly and spirally wound in reverse directions, to a total wall thickness of 3/16 of an inch, thoroughly saturated with a compound which shall be impervious to water and resist electrolytic action between the lead sheath and the zinc coating of the armor.

Armor

Outside of the jute specified above, an armor of Ex. B. B. galvanized iron wire, gage as ordered, shall be laid on without twisting, with a lay of ten times the diameter of the cable over the armor.

Galvanizing of Armor Wires

The galvanized wire used for the armor must comply with the specifications of the telegraph company for galvanized iron wire.

Jute Serving over Armor

Outside of the armor shall be placed two wraps of jute laid on in reverse directions and thoroughly saturated with a preservative compound consisting of 65 parts of mineral pitch, 30 parts of fine sand and 5 parts of tar.

The completed cable shall have a coating of soapstone to prevent the turns from sticking to each other on the reel.

Electrical Tests

After the sheath has been put on, but before it is served with jute and armored, the cable shall be immersed in a tank of water for 24 hours, at the end of which time the dielectric of each conductor shall be subjected to a strain of not less than 1,000 volts alternating-current applied for one minute from a suitable generator or transformer. Each wire shall then be tested for insulation against all other wires and the sheath of the cable, and must show a minimum of 1,000 megohms per mile at 60° F. with 100 volts applied for one minute.

Each conductor shall have a resistance and an electrostatic capacity which shall not exceed those specified in the following table:

Gage B. & S.	Resistance per mile in ohms at 68° F. of any wire	Mutual capacity per mile in m'f'ds of any pair	Average mutual capacity per mile in m'f'ds of all pairs
12	9.1	0.150	0.121
13	11.5	0.125	0.108
14	14.5	0.100	0.095

The finished cable on the shipping reel shall again be immersed and tested as above, and meet the same requirements.

The above tests to be made by a regularly authorized inspector of the telegraph company in the presence of the manufacturer's representative.

Filling of Ends

The ends of each length of cable must be filled with an insulating material which will seal the cable for a distance of 2 ft. or more from each end.

Reels

The finished cable to be free from all kinds of mechanical defects and to be furnished in lengths as specified, and wound on reels of suitable diameter. These reels are to have iron bushings of sufficient strength to safely carry the cable which is to be wound thereon with both the inner and the outer ends so arranged that electrical tests of the conductors can be made while on the reel.

A tag shall be securely attached to the reel, upon which shall be recorded the manufacturer's name, the exact number of feet of cable upon the reel, the number of conductors in the cable, the reel number, and the date of shipment to the telegraph company from the factory.

Immediately after the cable has been tested and inspected by the telegraph company's inspector, the ends of the cable shall be sealed with solder, and the inner end properly protected to prevent mechanical injury while in transit.

Manufacturer's Guarantee

The manufacturer to guarantee the perfection of the cable and that the cable will remain in good working condition during a telegraph or telephone service of one year after it is delivered. During the first year after the cable is purchased, the manufacturer to repair any defects due to faulty material or manufacture, or to reimburse the telegraph company for expenditures incurred in repairing such defects. The manufacturer not to be responsible for defects caused by mechanical injury.

SPECIFICATION FOR LEAD-COVERED TWISTED-PAIR PAPER CABLE

Conductors

Conductors to be of gage as ordered, of soft-drawn copper wire, preferably in one piece, free from joints; when joints are made they must be so brazed that there will be no reduction in the tensile strength of the wire.

Insulation

Each conductor shall be insulated with not less than three spiral wrappings, with a half-width lap, of the best grade manila paper, so that the total thickness of the insulating wall will be between 46 and 48 mils.

Twists of Pairs and Marking

The two wires of a pair shall be twisted together, the length of the lay not to exceed 6 in. The conductors of each pair to be—one red and one white, except those of the tracer pair in each layer, which are to be—one white and one dark blue, the latter spirally wound with coarse white thread.

Core

The twisted pairs shall be laid up into a cylindrical core with the layers in reverse directions. The whole core to be served with not less than three thicknesses of the best grade manila paper to a total wall thickness equal to that on the conductors and comprising not less than two wrappings with a half-width lap.

The cable must be laid up very compactly. For this reason the paper insulation should not be applied too tightly, so that when the pairs are tightly cabled together, the interstices between the conductors shall be filled with dense paper. In the event of the number of pairs called for not permitting the construction of a compact core, the number of pairs may be exceeded by the amount necessary to insure such construction.

Sheath

The lead covering must be of uniform composition and thickness, contain 3 per cent. of tin by weight, and be free from holes, splices, joints, porous places or other defects. It shall be not less than 1/8-in. thick and shall fit so tightly as to make the core compact.

Over-all Diameter

The manufacturers must ascertain the permissible over-all diameter of the finished cable when order is placed.

Filling of Ends

The ends of each length of cable must be filled with an insulating material which will seal the cable for a distance of 2 ft. or more from each end.

Electrical Tests

The finished cable shall be immersed in a tank of water for 24 hours, at the end of which time the dielectric of each conductor shall be subjected to a strain of not less than 1,000 volts alternating current applied for one minute

from a suitable generator or transformer. Each wire shall then be tested for insulation against all other wires and the sheath of the cable, and must show a minimum of 1,000 megohms per mile ar 60° F. with 100 volts applied for one minute.

Each conductor shall have a resistance and an electrostatic capacity which shall not exceed those specified in the following table:

Gage B. & S.	Resistance per mile in ohms at 68° F. of any wire	Mutual capacity per mile in m'f'ds of any pair	Average mutual capacity per mile in m'f'ds of all pairs
12	9.1	0.150	0.121
13	11.5	0.125	0.108
14	14.5	0.100	0.095
16	23.5	0.092	0.087

Reels

The finished cable to be free from all kinds of mechanical defects and to be furnished in lengths as specified, and wound on reels of suitable diameter. These reels are to have iron bushings of sufficient strength to safely carry the cable which is to be wound thereon with both the inner and the outer ends so arranged that electrical tests of the conductors can be made while on the reel.

A tag shall be securely attached to the reel, upon which shall be recorded the manufacturer's name, the exact number of feet of cable upon the reel, the number of conductors in the cable, the reel number, and the date of shipment to the company from the factory.

Immediately after the cable has been tested and inspected by the telegraph company's inspector, the ends of the cable shall be sealed with solder, and the inner end properly protected to prevent mechanical injury while in transit.

Manufacturer's Guarantee

The manufacturer to guarantee the perfection of the cable and that the cable will remain in good working condition during a telegraph or telephone service of one year after it is delivered. During the first year after the cable is purchased, the manufacturer to repair any defects due to faulty material or manufacture, or to reimburse the company for expenditures incurred in repairing such defects. The manufacturer not to be responsible for defects caused by mechanical injury.

SPECIFICATION FOR AERIAL (RUBBER COMPOUND DIELECTRIC) CABLE

All conductors to be of No. 14 B. & S. (64 mils diameter) thoroughly annealed copper, 98 per cent. pure, according to Matthiessen's standard, equal in strength, finish, and pliability to the best market grade, well tinned and uniformly coated to a diameter of 158 mils with a high-grade rubber permanent insulating compound, which shall adhere closely to the wire, and which shall not deteriorate under ordinary conditions.

Each insulated conductor, before being laid up into cable form, must have its dielectric subjected in water, after 24 hours immersion, to a strain of not less than 1,000 volts alternating current between the conductor and the water, applied for one minute from a suitable generator or transformer; and must show while in the tank, after such immersion, an insulation of not less than 300 megohms per mile at 60° F., with not less than 100 volts applied for one minute. Test to be made by standard testing instruments in the presence of an inspector of the telegraph company.

All conductors for test, either in coils or reels, must have tags securely attached, giving in plain figures the coil or reel numbers, the number of feet in each coil or reel, the gage of wire, and diameter of insulation; and such coils must so far as practicable bc in uniform lengths corresponding to the length of the cable.

One of the conductors in each layer of the cable must be suitably corded for tracing.

Each insulated conductor in the cable must be protected by a closely woven cotton braid of not less than 15 mils thickness, thoroughly saturated with a compound which is not soluble in water, which does not act injuriously upon the permanent insulating compound, braid or tape, and which is not objectionable to handle.

In case the number of conductors do not permit of layers in the mathematical ratio of 1, 7, 19, 37, 61, 91, etc., small strands of semi-saturated jute are to be used to render the lay-up of the cable symmetrical and also to protect the insulation of the conductors when the cable is subjected to bends and twists.

The cable must be wrapped over all with flexible cotton tape of first-class quality, saturated with first-class weatherproof compound. The tape must not be less than 20 mils thick, must have a lap of one-half its width, and firm adherence where lapped, so that it will not readily come apart. Over this the cable must have a durable protection of circular loom, braid, or tape covering, acceptable to the telegraph company, thoroughly saturated with the aforesaid compound.

The finished cable must not be sticky or objectionable to handle.

All cable made up as above, prior to shipment from factory, and after being placed upon reels, must have each length again tested for insulation by the inspector of the telegraph company.

Each conductor under test must show an insulation (when all of the other conductors of the length are grounded) of not less than 500 megohms per mile at 60° F., with not less than 100 volts applied for one minute. This test to be made without immersion.

The conductors of the completed cable must also be tested for continuity, and the inspector shall make such tests for capacity and conductivity as he thinks advisable.

The contractor will be required to furnish a table of coefficients of the resistance of the dielectric, showing its decrease above and its increase below 60° F., within the limits of variation of temperature to which the cable may be subjected during test.

The reels upon which the cable is shipped must be strong and well protected, and the cable neatly wound thereon with both ends so arranged that tests of the conductors on the reels may readily be made.

A tag must be securely fastened to each reel, upon which the contractor must record the exact number of feet from end to end of the cable upon the reel, the number of conductors in the cable, and the date of shipment to the company from the contractor's factory.

The contractor must give the usual guarantee that the cable will remain in good condition for one year after delivery, provided it is not used for currents of over 1 ampere, or having an electromotive force of over 500 volts; and must agree to repair or to reimburse the telegraph company for any expenditures incurred in repairing defects that may appear during that period, not caused by mechanical or other extraneous injury.

The cable must conform in quality and manufacture to a sample previously approved by the telegraph company.

SPECIFICATION FOR OFFICE CABLE

All conductors to be of No. 19 B. & S. (36 mils diameter) thoroughly annealed copper, 98 per cent. pure, according to Matthiessen's standard, equal in strength, finish, and pliability to the best market grade, well tinned and uniformly coated to a diameter of 101 mils with a high-grade permanent insulating compound, which shall adhere closely to the wire, and which shall not deteriorate under ordinary conditions.

Each insulated conductor, before being laid up into cable form, must have its dielectric subjected in water, after 24 hours immersion, to a strain of not less than 1,000 volts alternating current between the conductor and the water, applied for one minute from a suitable generator or transformer; and must show while in the tank, after such immersion, an insulation of not less than 300 megohms per mile at 60° F., with not less than 100 volts applied for one minute. Test to be made by standard testing instruments in the presence of an inspector of the telegraph company.

All conductors for test, either in coils or reels, must have tags securely attached, giving in plain figures the coil or reel numbers, the number of feet in each coil or reel, the gage of wire, and diameter of insulation; and such coils must so far as practicable be in uniform lengths corresponding to the length of the cable.

One of the conductors in each layer of the cable must be suitably corded for tracing.

Each insulated conductor in the cable must be protected by a closely woven cotton braid of not less than 15 mils thickness, thoroughly saturated with a compound which is not soluble in water, which does not act injuriously upon the permanent insulating compound, braid or tape, and which is not objectionable to handle.

The conductors must be so laid up as to make the completed cable sufficiently flexible to permit it to be bent without buckling to the diameter given in the following table.

Diameters of drums on which office cables must bend without buckling:

5 conductor	2 in.
10 conductor	5 in.
25 conductor	9 in.
50 conductor	14 in.

The cable must be wrapped over all with flexible cotton tape of first-class quality, saturated with first-class weatherproof compound. The tape must not be less than 20 mils thick, must have a lap of one-half its width, and firm adherence where lapped, so that it will not readily come apart.

The finished cable must not be sticky or objectionable to handle.

All cable made up as above, prior to shipment from factory, and after being placed upon reels, must have each length again tested for insulation by the inspector of the telegraph company; and each conductor under test must show an insulation (when all of the other conductors of the length are grounded) of not less than 500 megohms per mile at 60° F., with not less than 100 volts applied for 1 minute in the usual manner.[1] The conductors of the completed cable must also be tested for continuity, and the inspector shall make such tests for capacity and conductivity as he thinks advisable.

The contractor will be required to furnish a table of coefficients of the resistance of the dielectric, showing its decrease above and its increase below 60° F., within the limits of variation of temperature to which the cable may be subjected during test.

The reels upon which the cable is shipped must be strong and well protected, and the cable neatly wound thereon with both ends so arranged that tests of the conductors on the reels may readily be made.

A tag must be securely fastened to each reel upon which the contractor must record the exact number of feet from end to end of the cable upon the

[1] Omitting immersion.

reel, the number of conductors in the cable, and the date of shipment to the telegraph company from the contractor's factory.

The contractor must give the usual guarantee that the cable will remain in good condition for one year after delivery, provided it is not used for currents of over 1 ampere, or having an electromotive force of over 500 volts; and must agree to repair or to reimburse the telegraph company for any expenditures incurred in repairing defects that may appear during that period, not caused by mechanical or other extraneous injury.

The cable must conform in quality and manufacture to a sample previously approved by the telegraph company.

SPECIFICATION FOR OFFICE WIRES

Conductors

Conductors to be of gage as ordered, of soft-drawn copper wire not less than 98 per cent. pure, preferably in one piece free from joints. When joints are made, they must be so brazed that there will be no reduction in the tensile strength or conductivity of the wire.

Wire must be tinned and uniformly coated with high-grade insulating compound to the thickness specified.

Braid

Colored braid, when required, must be of the specified thickness, closely woven and with smooth surface. It is to be made of good quality strong cotton thread fast colored with non-injurious dyes.

Braid on office wire must be made of closely woven, fire-proofed, strong cotton thread.

Saturated braid must be filled with a first-class, water-proof, insulating compound which will give a smooth surface, but which will not be injurious to braid or rubber, become tacky at the highest summer or crack at the lowest winter temperatures.

Each wire of twisted pairs must be braided separately and one of the wires suitably marked for tracing.

Electrical Tests

The wire after being braided (except in the case of office wire) shall be immersed in a tank of water for 24 hours at the end of which time its dielectric shall be subjected to a strain of not less than 500 volts alternating current for two seconds for 50-megohm wires, and 1,000 volts alternating current for five seconds for the 500- and the 750-megohm wires.

The insulation of each length shall be tested in the usual manner with 100 volts applied for one minute at 60° F.

Office wire must be immersed and tested as above *before* the braid is put on. After braiding, samples must be submitted for approval.

Coils

Coils under test must be serially numbered and so far as practicable in uniform lengths of 500, 1,000 or 2,000 ft. Subsequently the wire must be cut into lengths to conform with the order.

Each accepted coil must be neatly laid up and wrapped in paper or burlap. After wrapping, a tag giving length, weight, gage, kind, color, and manufacturer's name must be securely fastened to the inside of each coil.

The coils wrapped and tagged as above must be packed in barrels which are to be plainly marked, showing the size or gage, kind, color and total number of feet in each barrel.

TABLE OF STANDARD RUBBER COMPOUND INSULATED WIRES

Name	Conductor	Minimum diameter insulated wire without braid mils[1]	Braid		Minimum megohms per mile 60° F. 100 volts
	B. & S. gage		Thickness mils	Color and finish	
Office	16	113	13	Gray flame proof	500
Bridle	14	158	20	Black saturated	750
Pothead and battery stems.	14	140		No braid	750
Call circuit	16	113	20	Black saturated	50
Outside twisted pair.	14	158	20	Black saturated	750
Annunciator	18	102	15	Glazed cotton, color as ordered.	50
Annunciator twisted pair.	18	102	15	Glazed cotton, color as ordered.	50

[1] Maximium allowable diameter of insulated wire without braid 5 mils above minimum.

CHAPTER XXIV

ELECTROLYSIS OF UNDERGROUND CABLE SHEATHS

When two pieces of metal are immersed in an electrolyte consisting of slightly acidulated water, and a current of electricity is passed between them, minute particles of one of the metals are decomposed and deposited upon the surface of the other metal. The action is the same as that which takes place in the process of electroplating. The detached particles are carried from one metal to the other in the same direction the current travels—from positive to negative plate.

A similar action takes place between the sheaths of buried cables and the tracks of electric railroad systems. The positive pole of the railroad power dynamo is connected to the feeder system and the negative pole of the dynamo to the steel rails, making a circuit via the car trolley or shoe equipment through the car motors and back to the generating station over the track.

Where the rails are in contact with the earth either directly or indirectly (by way of metal supporting structures) the current in the rails has a tendency to leak away from the track and travel back to, or in the direction of, the power station. Obviously, wherever metal pipe systems are buried in the earth adjacent to electric railroad tracks, the former in many cases will form a branch of a joint-circuit constituting the return path of the railroad current. If the rails were perfectly insulated from the earth or were laid in perfectly dry ground this action could not take place, but in most localities there is a sufficient amount of moisture beneath the surface of the earth to act as an electrolyte. The earth serves the purpose of an electroplating tank, as it has all the elements required, namely, the car tracks and cable sheaths separated by a more or less moisture-saturated compound.

The fact that the sheaths of the buried cables act as conductors for a portion of the return current is not of much concern, but if while serving as a conductor the sheath is immersed in an electrolyte, the danger is that a portion of the current will leave the conductor and pass through the electrolyte to another conductor, for in that case it will carry particles of the sheath to the surface of the second conductor, and while this action does not particularly menace the usefulness of the latter it soon results in disintegration of the cable sheath with the result that moisture is permitted to enter the cable causing leaks, crosses, short circuits and grounding of the conductors contained in the cable.

The amount of current which escapes from a track to adjacent pipe lines depends upon the relative electrical distance of the track circuit, the earth and the pipe line, with regard to the location of the power house. A very small current volume, however, will produce electrolytic action. For example, one ampere flowing one hour dissolves 0.035 oz. of cast iron, 0.105 oz. of wrought iron, and 0.125 oz. of lead. In practice, of course, the current does not often flow from any one point, but is spread out over a considerable length of cable or track; but it will be realized that even where the surfaces affected have considerable area, where the action continues for any great length of time the result will be disastrous. The ideal remedy is to provide a return circuit for the railway current of sufficient capacity to reduce leakage to the lowest possible degree, by properly bonding the rails or by installing an auxiliary return wire of large section bonded to the rails at intervals, but even where this is done, at points remote from the power house neighboring pipe systems are still likely to form branches of a joint-circuit back to the negative terminal of the dynamo.

Where the current passes from the tracks to the cable sheath or to a pipe line, no damage will be done to either of the latter, but the tracks themselves will be eaten away. Where the current leaves the sheath or pipe, however, and passes to the tracks or to other pipe systems, damage will be done to the sheath or pipe at the point or points where the current leaves them.

When any interruption occurs to the track return circuit, as, for instance, when a bond is broken, or a rail is broken or temporarily removed, a large proportion of the return current is shunted around the break through adjacent pipe lines and the large current volume diverted through the latter within a very short time causes serious damage at the point where the current leaves the sheath or pipe in returning to the track rails at a point on the generator side of the interruption.

In order to determine where electrolysis is liable to occur, it is well to obtain or prepare a map showing the location of manholes and cables and the routes they take. Upon this map the electric railway lines may be traced with red ink. At all manholes measurements should be made between the rails and cables, water-pipes, gas-pipes, manhole frame (if metal), water in manhole, other cables and in fact all metal objects that are buried in the ground in that neighborhood which would in any way affect the cables.

In making the measurements a voltmeter with a low reading scale should be used, attaching a wire to the positive terminal of the meter and another wire to the negative terminal. The free ends of the wires should be attached to strips of lead or to steel rods (old steel files with sharp points make good substitites) as it is found that when the ends of the copper wires are used a local action sometimes takes place which interferes with the true readings.

If, when the wire attached to the positive terminal of the voltmeter is placed in contact with the rail, water-pipe, water in the manhole, manhole

frame, or other object, while the wire attached to the negative terminal of the voltmeter is placed in contact with the cable sheath; the voltmeter pointer is deflected to the right, the indication means that a current is flowing from the rail, pipe or manhole frame, etc., to the cable sheath. If the deflection is in the same direction as contact is made with each object, a record should be made to the effect that the cable is — (negative) to the earth at that point, the rail, and to other pipe systems. If it is found when contact is made in any instance that the pointer deflects to the left the indication means that current is flowing from the cable sheath to the neighboring object and that the sheath is being slowly eaten away. The exact difference of potential may be learned by reversing the wires in the binding-posts of the voltmeter so that the pointer may move from its zero position at the extreme left of the scale, to a point on the right which indicates the existing voltage.

If a reliable low-reading voltmeter is not at hand, and a Weston galvanometer is available, the latter may be used for electrolysis tests by connecting an external resistance of 5,000 ohms in series with the galvanometer. Then, with no shunt around the galvanometer movement coil, the scale will have a reading of 0.1 volt, in 0.01-volt divisions. Using the one-tenth shunt, the scale-reading will have a value of 1 volt in divisions of 0.1 volt. Using the one one-hundredth shunt the scale will have a value of 10 volts in divisions of 1 volt.

CABLE TO CABLE, AND CABLE TO RAIL BONDING

Undoubtedly there are instances of electrolytic corrosion of cable sheaths not attributable to stray railway currents, such, for instance, as occur where cables are laid in earth strewn with cinders, or where the character of the soil in which the cable is buried is such that galvanic action takes place between the cable sheath and neighboring metallic substances, or in cases where during the winter months frozen water-pipes are thawed out by heating them by passing currents of large volume through the frozen sections for a number of hours,[1] but inasmuch as the bulk of the trouble experienced is due to electric-railway return currents, it is good practice to take all possible precautions to insure a low resistance return path to the power station for these currents.

In some instances it has been found advisable to run bare stranded copper-wire cables parallel to and bonded to the cable for the purpose of shunting stray currents which otherwise would flow through the sheath of the cable.

Satisfactory operation of electric railroads requires that adequate bonding between abutting rails be maintained in order that the circuit resistance

[1] Where this method of thawing water-pipes is practised it has been found that neighboring pipe systems are endangered to an extent dependent upon the proximity of such lines to the water-pipes being treated, upon the character of the sub-soil, and upon the electrical continuity of any intervening joints in the water-pipe between the points upon their surfaces where the thawing current is applied.

between the negative terminals of car motors and the negative terminal of the power generator will be as low as possible, and unless the condition of all bonds is constantly inspected, high-resistance contacts are liable to develop and remain undetected until considerable damage has been done to adjacent cable sheaths. So far as rail bonding is concerned it should be remembered that the conductivity of copper is about ten times that of the steel used in making the rails, the copper bond employed should, therefore, be of one-tenth the sectional area of the rail if the bond is to have the same current-carrying capacity as the rail.

Where two or more cables terminate in, or pass through a manhole the various cables should be bonded together, preferably with a strip of lead 2 or 3 in. in width. Where lead is used in cable to cable bonding there is less likelihood of galvanic action than where copper bonds are used.

Where cable sheaths are found to be positive to track rails, it is customary to bond the cable to the rails, and while there are certain objections to this practice and some risk incurred, the general experience is that the advantages outweigh the disadvantages.

APPENDIX A

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APPENDIX B

SPECIFICATIONS FOR THE CONSTRUCTION OF HIGH-TENSION POWER TRANSMISSION LINES ABOVE TELEGRAPH WIRES[1]

GENERAL

(a) These specifications apply to constant-potential power transmission lines of over 5,000 volts.

(b) These specifications prescribe a certain minimum standard of construction for the high-tension line which is required in order to provide a reasonable degree of security against the failure of any portion of the high-tension construction that might allow the high-tension wires to come into contact with the telegraph wires.

(c) It is not the purpose of these specifications to restrict the high-tension construction narrowly in details, but to stipulate the fundamental principles which must be followed in order to attain reasonable safety.

(d) Each portion of the high-tension line shall have sufficient strength to resist the maximum mechanical stresses to which it may be subjected, due allowance being made for a factor of safety suited to the degree of uniformity of the material, the character of the material with respect to deterioration and the nature of the stress, as hereinafter specified.

(e) Obviously the maximum mechanical loads upon the high-tension construction will usually occur when the wires are coated with ice and subjected to the maximum wind velocity at right angles to the line at the minimum temperature.

(f) The maximum stresses in the high-tension construction shall be computed on the basis of a wind pressure of 20 lb. per square foot of plane area, or 12 lb. per square foot of projected area for cylindrical surfaces. These values are based upon a maximum actual wind velocity of 70 miles per hour and are to be used in connection with the following coincident conditions:

(1) Maximum coating of ice, 1/2 in. in thickness.

(2) Minimum temperature, zero degrees Fahrenheit.

NOTE.—In a few sections, in southern portions of the country, minimum temperatures of zero degrees and ice formation are not encountered. For transmission lines constructed in such regions the above requirements may be suitably modified to accord with local climatic conditions. In no case shall the minimum temperature be taken above 30° F.

[1] From Standard Specifications.

(g) The general types of construction which shall be employed, the factors of safety to be observed, and the minimum sizes and strengths of materials, shall be as specified below.

(h) Where galvanizing of iron or steel is required, it shall conform to the requirements of the appended specifications for galvanizing for iron and steel.

TOWERS AND POLES

(i) **Material.**—The poles supporting the high-tension conductors where these are above the telegraph line shall preferably be of steel. Reinforced concrete or wood poles may be employed under suitable restrictions as hereinafter specified.

(j) **Factors of Safety.**—(1) Poles shall have the following minimum factors of safety according to the nature of the materials employed:

Steel	3
Reinforced concrete	4
Completely creosoted wood	5
Other wood	6

(2) The poles, at the terminals of the portion of the high-tension line covered by these specifications, shall be of such strength as not to break under the maximum load conditions, if any, or all, of the conductors in the spans outside this portion should break.

(k) **Wood or Reinforced Concrete Poles.**—(1) Wood poles shall not be used where inflammable materials, such as structures, are situated within a distance sufficient to cause an appreciable fire hazard to the pole.

(2) If wood poles are employed, surrounding underbrush and grass must be removed for a sufficient distance to avoid fire hazard.

(3) Wood or reinforced concrete poles must be provided with a grounded copper wire or an approved equivalent metal strip, placed at the side of the pole and extended to the top of the pole and over the top of the pole. In the case of wood poles this grounded conductor shall be extended down the opposite side of the pole to the top of the lowest cross-arm, Fig. 419. This grounded conductor shall be of sufficient conductivity to carry safely the maximum short-circuit current. This grounded conductor provides lightning protection and, in the case of wooden poles, serves to prevent arcing and setting fire to the pole in case a high-tension wire becomes detached from its insulator and rests against the side of the pole.

(l) **Guys.**—(1) Where guys can be placed, the total strength of the guyed structure shall be sufficient to sustain the maximum stress with factors of safety not less than those specified in section (j).

(2) All guys shall be anchor guys, guys to anchored stubs or rock guys.

(3) Methods of anchoring, locations for anchors, and depth and character of setting shall be such as to render effective the full strength of the guy.

(4) Guys shall be of galvanized steel strand not smaller than five-sixteenths in. in diameter.

(5) Strain insulators are not required, but if these should be placed in guys, each strain insulator shall have a breaking strength not less than that of the guy in which it is placed. Every guy which passes over or under any electric wires, other than these carried upon the guyed pole shall be so placed and maintained as to provide at all times a clearance of not less than 2 ft. between the guy and such electric wire.

(m) **Minimum Size Wood Poles.**—No wood pole, whether guyed or not, shall be less than 8 in. in diameter at the top.

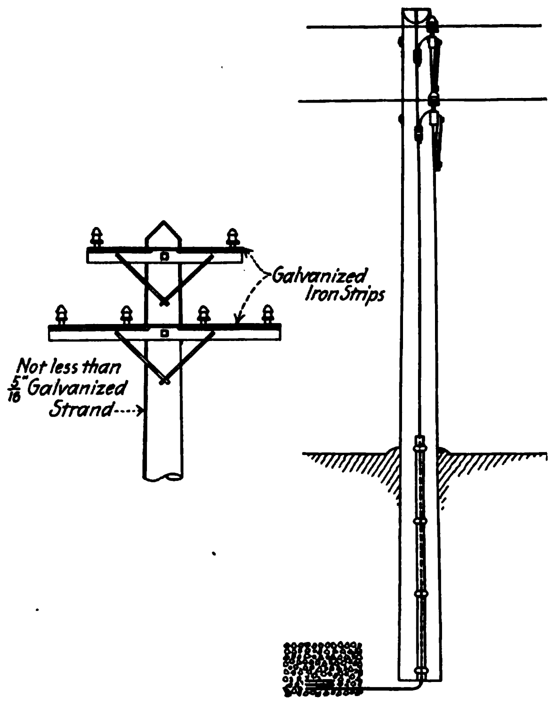

FIG. 419.

(n) **Replacement of Wood Poles.**—Wood poles shall be periodically inspected and shall be replaced before their strength falls below two-thirds of their initial strength.

(o) **Structural Steel Poles or Towers.**—(1) All structural steel shall conform to specifications for open-hearth railway bridge or medium steel adopted by the Association of American Steel Manufacturers.

(2) All steel poles and towers shall either be galvanized or thoroughly painted with not less than three coats of an approved metal preservative.

Painting shall consist of at least one shop coat and two field coats, preferably all of different shades of color.

(3) Steel poles and towers shall be thoroughly grounded in a manner satisfactory to the telegraph company.

(p) **Unit Strength of Materials.**—The fiber stresses to be employed in computing the strengths of poles shall not be more than as follows:

		Working fiber stress
Steel	medium	20,000 lb.
	railway bridge	18,500 lb.
Cedar		600 lb.
Chestnut		800 lb.
Creosoted yellow pine		1,200 lb.

The working-fiber stresses given above include allowances for factors of safety in accordance with the preceding requirements.

(q) **Setting Poles.**—(1) Great care shall be taken in setting poles at high-tension crossings to secure firm foundations.

(2) Exposure to washouts shall be avoided.

(3) Poles shall not be set on sloping banks when other location is practicable. Where poles are necessarily set on sloping banks they shall be well reinforced by cribbing.

(4) In sandy or swampy soil concrete foundations shall be provided for wood poles. Each foundation shall contain not less than two cubic yards of concrete.

(5) Concrete shall not be leaner than one part of cement to two and one-half parts of sand, to five parts of broken stone. An equivalent gravel concrete may be used. Cement shall be Portland cement conforming to the standard specifications of The American Society for Testing Materials. Sand shall be clean and sharp. All concrete shall be mixed and placed thoroughly wet.

WIRES

(r) **Spans Covered by these Specifications.** (1) **Crossings.**—The construction herein specified applies to the cross-over span. Where the distance from the topmost high-tension wire at either pole of the cross-over span to the nearest wire on the telegraph line is less than one and one-half times the height of the topmost high-tension wire above the ground at the high-tension pole, the requirements specified for the cross-over span shall be considered as applying also to the next high-tension span adjacent to that pole, Fig. 420.

(2) **Parallel Lines.**—Where the high-tension line must necessarily be constructed higher than and parallel to the telegraph line, and separated from the latter by a distance less than the height of the high-tension poles, the construction shall conform to the requirements for the cross-over span

as herinafter specified. The requirements shall also apply to each span next adjacent to the portion above the telegraph line, unless the distance from the nearest telegraph wire to the topmost high-tension wire on the high-tension poles at the end of the over-built section, is greater than one and one-half times the height of the topmost high-tension wire from the ground, Fig. 421.

(s) **Factors of Safety.**—The length of the cross-over span and the sag of the wire shall be so proportioned, with reference to the kind and size of wire

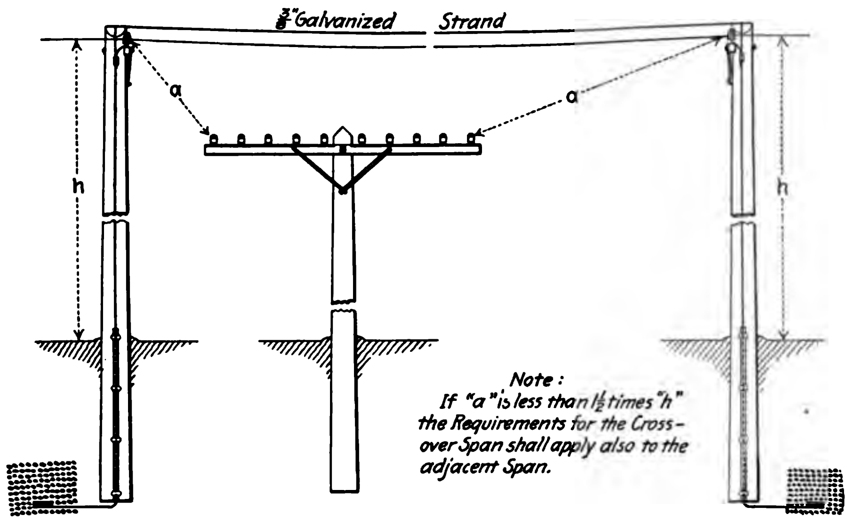

FIG. 420.

and method of suspension, that a factor of safety of at least 2, and no stresses beyond the elastic limit of the material will be obtained under the maximum conditions specified in clause (f).

(t) **High-tension Conductors.**—(1) Stranded wire shall be used for the high-tension conductors in the cross-over span and other spans covered by the requirements of these specifications. Each shall consist of not less than seven component wires.

(2) The minimum sizes of conductors shall be

Copper....................	Not less than No. 0 B. & S. gage.
Aluminum..................	Not less than No. 00 B. & S. gage.

(3) There shall be no joints in the conductors in the spans requiring special construction.

(u) **Precautions against Injury to Wires from Arcing.** (1) **Separation.**—The minimum separation between wires on centers shall be as follows:

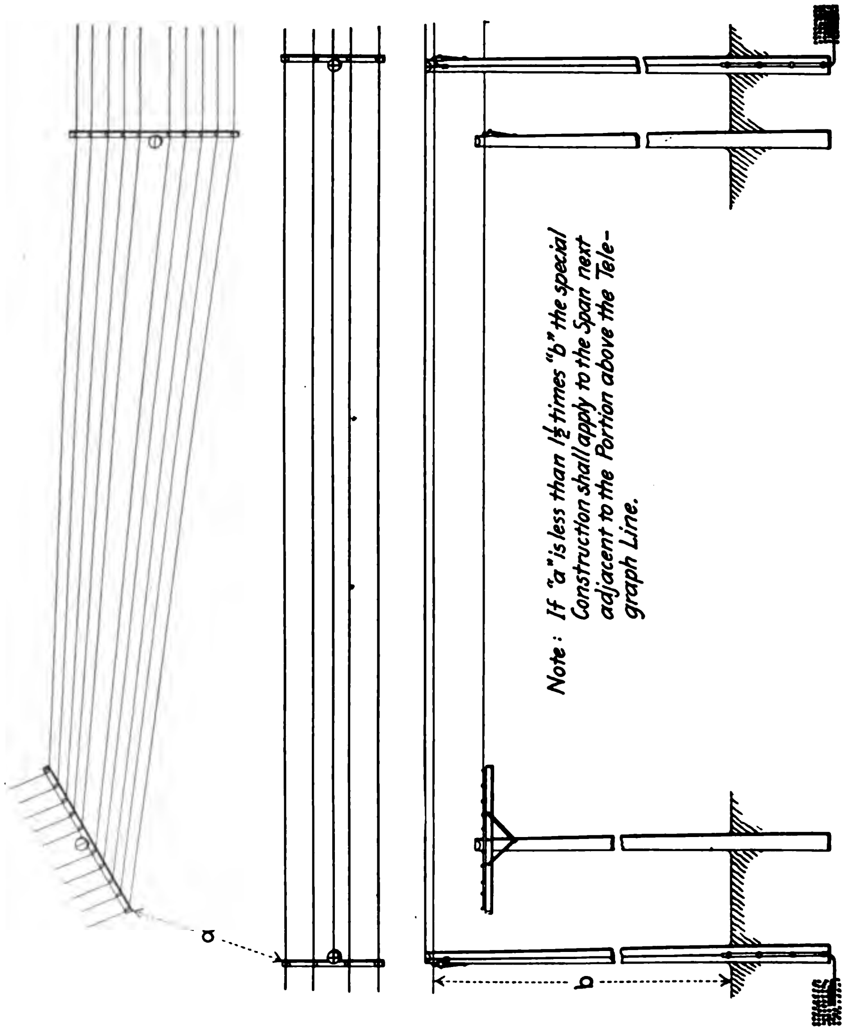
Note: If "a" is less than 1½ times "b" the special Construction shall apply to the Span next adjacent to the Portion above the Telegraph Line.
a
b

FIG. 421.

Voltage between wires	Minimum separation on centers
Under 12,500	2 ft.
12,500 to 19,000	2½ ft.
20,000 to 29,000	3½ ft.
30,000 to 39,000	4 ft.
40,000 to 59,000	5 ft.
60,000 and over	6 ft.

(2) **At Insulators.**—(1) At the poles forming the termini of the spans covered by these specifications, each conductor shall be so protected at the point of attachment to the insulator, that if the insulator breaks down electrically, the resulting arc will not burn the conductor. This may be accomplished by providing between the conductor and the insulator a metal cap which will interpose at least 1/2 in. of metal between the line conductor and the head of the insulator. Also the conductor shall be protected from an arc for a distance of not less than 24 in. on each side of the center of the insulator head by a serving of wire or a sheet metal envelope not less than No. 6 B. & S. gage in thickness.

(2) The wire serving or sheet metal envelope shall be of the same kind of metal as the line conductor which it protects.

(v) **Minimum Clearance above Telegraph Wires.**—The high-tension construction shall be such that at a temperature of 130° above the minimum temperature (clause F.), the lowest high-tension wire shall clear the highest telegraph wire or cable by not less than 8 ft. Where practicable, no telegraph pole shall be closer than 15 ft. horizontally to the nearest high-tension wire. The telegraph crossarms may be spaced 15 in. on centers at crossings in order to allow high-tension poles of minimum height to be used.

(w) **Unit Strength and Elasticity of Materials.**—(1) The tensile strengths to be employed in computing the wires shall not be more than as follows:

	Working strength, pounds per square inch
Hard-drawn copper stranded conductor	30,000
Hard-drawn aluminum stranded conductor	12,000

(2) The modulus of elasticity may be taken as follows:

	Modulus of elasticity
Hard-drawn copper stranded conductor	12,000,000
Hard-drawn aluminum stranded conductor	7,500,000
Steel strand	22,000,000

(x) **Coefficient of Linear Expansion.**—The coefficient of linear expansion per Fahrenheit degree may be taken as follows:

Copper	0.0000096
Aluminum	0.0000130
Steel	0.0000064

(y) **Method of Attachment.**—In all spans covered by these specifications, the high-tension conductors shall be attached to the insulators on each side of the span by mechanical clamps or approved ties. Ties such as are ordinarily employed for signaling wire shall not be used. The clamps or ties shall have sufficient grip and shall be set up sufficiently tight so as to hold the conductors up to stresses equal to the working strengths of the conductors and shall be of such a design as not to injure the wire. If ties are used, the tie wires shall be attached to the line conductor at a distance from the head of the insulator not less than one-tenth of the distance specified in section (u), and in no case less than 4 in.

CROSSARMS

(z) **Material.**—The crossarms supporting the wires or strands shall be of steel or creosoted wood.

(aa) **Factors of Safety.**—Crossarms shall have the following minimum factors of safety according to the nature of the material employed:

Steel	3
Creosoted wood	5

(bb) **Loads on Crossarms.**—The crossarm and its attachment shall have sufficient strength to provide against breaking, in the case of the breaking of any or all of the wires in the span adjacent to the cross-over span.

(cc) **Steel Crossarms.**—Steel crossarms should preferably be used. Steel crossarms shall be thoroughly grounded. All portions of the ground connection shall have sufficient conductivity to carry safely the maximum short-circuit current.

(dd) **Wood Crossarms.**—(1) If wood crossarms are employed they shall be treated with creosote or dead oil of coal tar in accordance with approved specifications.

(2) Wood crossarms shall be provided with grounded galvanized iron plates or grounded copper wires on their upper surfaces. Plates shall not be less than 1/4 of an inch in thickness, and of a cross-sectional area not less than that of the ground wire. If copper wires are employed they shall be of sufficient conductivity to carry safely the short-circuit current. Ground wires or plates shall be firmly attached to the crossarms.

(ee) **Protection of Metal from Corrosion.**—All portions of steel crossarms and their fittings, and the center bolts, braces, ground plates and other fittings of wood crossarms shall be thoroughly galvanized.

(ff) **Protection Against Line Conductors Falling Clear of Crossarms.**—At spans where these specifications apply, angles in the route of the high-tension line shall be avoided wherever practicable. At these spans, if mechanical clamps are not employed, the outer high-tension line conductors shall in all cases be attached so as to pull against the insulators.

PINS

(gg) **Material.**—Steel pins shall be used.

(hh) **Strength of Pins.**—Pins shall be sufficiently strong to provide a factor of safety of 3 against stresses produced by the maximum wind pressure on the wires loaded with ice and also against stresses produced by the breaking of the wire in the span adjacent to the crossing span.

(ii) **Grounding of Pins.**—Pins shall be thoroughly grounded.

INSULATORS

(jj) **Material.**—Porcelain insulators shall be used for supporting the high-tension conductors.

(kk) **Mechanical Strength.**—The insulators shall be sufficiently strong so that, when mounted, they shall be able to withstand without injury twice the maximum mechanical stress to which they will be subjected with the line conductors attached as herein specified.

(ll) **Dielectric Strength.**—Where tested under approved methods each insulator shall be capable of resisting three times the normal voltage when tested dry and twice the normal voltage under spray test.

(mm) **Disk Insulators.**—Where suspension insulators are used, each individual disk shall be provided with interlinked attachments so that, in case the porcelain should be shattered, the conductor would remain mechanically attached to the crossarm. The support next adjacent to the crossarm shall be thoroughly grounded.

LIGHTNING PROTECTION

(nn) Each pole and tower, in the portion of the high-tension line covered by these specifications, shall be provided with a grounded lightning-protective device extending above the top of the pole or tower and not less than 3 ft. above the highest conductor.

CONSTANTS, UNIT STRESSES AND FORMULÆ TO BE USED IN COMPUTING STRENGTH OF TRANSMISSION LINES

UNIT STRESSES

POLES AND TOWERS

	Allowable working fiber stress
Steel.. medium	20,000 lb. per square inch.
Steel.. railway bridge	18,500 lb. per square inch.
Cedar	600 lb. per square inch.
Chestnut	800 lb. per square inch.
Creosoted yellow pine	1,200 lb. per square inch.

WIRE AND STRAND

	Allowable tensile strength
Stranded copper	30,000 lb. per square inch.
Stranded aluminum	12,000 lb. per square inch.
Steel strand	(According to the character of the material, a factor of 3 being used).

	Modulus of elasticity
Stranded copper	12,000,000
Stranded aluminum	7,500,000
Steel strand	22,000,000

	Coefficient of linear expansion per degree Fahr.
Copper	0.0000096
Aluminum	0.0000130
Steel	0.0000064

CROSSARMS

	Allowable working fiber stresses
Steel.. medium	20,000 lb. per square inch.
Steel.. railway bridge	18,500 lb. per square inch.
Creosoted yellow pine	1,200 lb. per square inch.

PINS

	Allowable working fiber stress
Steel	20,000 lb. per square inch.

Wind Pressure.—

$P =$ pressure in pounds per square foot.

$V =$ actual velocity of wind in miles per hour.

For plane surfaces

$$P = 0.004V^2.$$

For cylindrical surfaces

$$P = 0.0025V^2$$

(P = pressure per square foot of projected area.)

For velocity of 70 miles per hour

$P = 20$ lb. for plane surfaces.

$P = 12$ lb. for cylindrical surfaces.

Sleet and Ice.—

Weight of ice per cubic foot, 58 lb.

Weight of block of ice 1 ft. long and 1 sq. in. section, 0.403 lb.

Poles.—A pole is essentially a beam fixed at one end. The ordinary beam formulæ apply.

The strength of a pole is given by the formula

$$M = \frac{pI}{y}$$

where M = moment of the forces about the ground line (or other point at which the strength is being considered).

p = maximum fiber stress.

I = moment of inertia of section of pole.

y = distance from center to most strained fiber.

For a pole of circular cross-section

$$M = \frac{p\pi D^3}{384}$$

where D = the diameter of the pole in inches and the moment arms of the forces are expressed in feet.

p is the maximum ultimate fiber stress or the allowable working fiber stress according as the ultimate strength or safe working strength of the pole is desired.

Forces Acting on a Pole Transversely.—

Wing pressure on pole.

Wing pressure on conductors.

The approximate moment at the ground due to wind pressure on the pole would be

$$M_p = \frac{PH^2(D_1 + 2D_2)}{72}$$

P = wind pressure per square foot of projected area.
H = height of pole above ground in feet.
D_1 = diameter of pole at ground.
D_2 = diameter of pole at top.

The moment at the ground due to wind pressure on the wires would be

$$Mc = \frac{PLnD_i(S_1 + S_2)}{24}$$

L = height of wires above ground in feet.
n = number of wires.
D_i = diameter of conductor loaded with ice.
S_1 = and S_2 = lengths of adjacent spans in feet.

The total moment is the sum of M_p, Mc_1, Mc_2, etc.

Conductors.—A metallic conductor is elastic and also expands and contracts with changes in temperature. When a wire in a span is cooled it contracts, making the sag less and increasing the tension in the wire. The elongation of the wire due to the increased tension tends to increase the sag and to diminish the tension. When a wire is loaded by sleet or by wind pressure the increased tension in the wire causes it to stretch and the sag to increase. The increase in the sag tends to reduce the tension.

The formulæ for computing these various changes are as follows:

Relation between temperature and sag

$$a = \frac{8}{3}\frac{1}{cY^2}(d_1^2 - d_0^2) + \frac{1}{8}\frac{1}{ec}\frac{p}{s}Y^2\left(\frac{1}{d_0} - \frac{1}{d_1}\right)$$

where sag and span are expressed in feet.

$$\text{or} \quad a = \frac{1}{54c}Y^2(d_1^2 - d_0^2) + \frac{3}{2}\frac{1}{ec}\frac{p}{s}Y^2\left(\frac{1}{d_0} - \frac{1}{d_1}\right)$$

where sag is in inches and span in feet.

Symbols.—

a = temperature variation for small changes in sag.
t_0 = initial temperature.
t_1 = $t_0 + a$.
Y = length of span.
d_0 = sag at temperature t_0.
d_1 = sag at temperature t_1.
c = coefficient of linear expansion per degree F.
e = modulus of elasticity.
p = load per foot of wire.
s = cross-section of wire in square inches.

By assuming small changes in the sag, successive values of a may be found from which a curve showing the variation of sag with temperature may be made.

Relation between tension and sag.

$$T = \frac{pY^2}{8d} \text{ (sag and span in feet)}$$

Length of wire.—

$$L = Y\left(1 + \frac{8}{3}\frac{d^2}{Y^2}\right) \text{ (span and sag in feet)}$$

Elongation due to change in tension.

$$E = \frac{TL}{es}$$

Example.—Poles:

Length of pole, 40 ft.
Height of pole above ground, 34 ft.
Length of adjacent spans, 100 ft. and 120 ft.

Wires:

One No. 0 wire on top of pole.
Two No. 0 wires on crossarm 3 ft. below top.
Two No. 12 telegraph wires on crossarm 7 ft. below lower power wires.

To find dimensions of cedar pole to give factor of safety of 6 with a wind velocity of 70 miles in a direction at right angles to the line and 1/2 in. thickness of ice on each wire.

Wind pressure on upper wire.

Diameter of No. 0 wire = 0.37.
Diameter of No. 0 wire covered with 1/2 in. ice = 1.37.

$$Mc_1 = \frac{PLnD_i\ (S_1 + S_2)}{24}$$

$$Mc_1 = \frac{12.3 \times 34 \times 1 \times 1.37(100 + 120)}{24} = 5{,}253.$$

Wind pressure on two middle wires:

$$Mc_2=\frac{12.3\times31\times2\times1.37(100+120)}{24}=9,579.$$

Wind pressure on telegraph wires:

Diameter of No. 12 wire = 0.104 in.

Diameter of No. 12 wire covered with 1/2 in. ice = 1.104 in.

$$Mc_3=\frac{12.3\times24\times2\times1.104(100+120)}{24}=5,975.$$

Wind pressure on pole assuming diameters at butt and top to be 17 in. and 8 in.

$$Mp=\frac{PH^2(D_1+2D_2)}{72}$$

$$Mp=\frac{12.3\times34^2\times33.}{72}=6,500$$

(If the result gives dimensions of poles much different from the values assumed a second approximation should be made.)

Total moment = 27,307

$$M=\frac{P\pi D_1^3}{384}$$

For cedar $p=600$

$$\frac{600\pi D_1^3}{384}=27,307$$

$4.91\ D_1^3=27,307$

$D_1=17.1$ in.

Circumference at ground line = 54 in.

Example.—Conductors: To find sag of wire at 60° F. such that the wire will have a factor of safety of 2 at 0° F. with ice 1/2 in. thick all around the wire and wind blowing at right angles to the line at a velocity of 70 miles an hour.

Size of wire No. 0.

Wire of stranded copper.

Length of span 200 ft.

Diameter of wire = 0.370 in.

Cross-section of copper = 0.083 sq. in.

Diameter of wire + 1/2 in. ice = 1.370 in.

Cross-section of wire + 1/2 in. ice = 1.47 sq. in.

Cross-section of ice = 1.39 sq. in.

Weight of wire per foot = 0.323 lb.

Weight of ice per foot = $0.403 \times 1.39 = 0.560$ lb.
Weight of ice and wire per foot = $0.560 + 0.323 = 0.883$ lb.

Wind pressure per foot = $\frac{1.370}{12} \times 12.3 = 1.40$

Resultant pressure per foot $= \sqrt{1.40^2 + 0.883^2} = 1.65$ lb.

Breaking weight of No. 0 wire = 4,980 lb.

With factor of safety of 2, the allowable tension in the wire = 2,490 lb.

At 0° the wires weighted with wind and ice

$$d = \frac{pY^2}{8T}$$

$$d = \frac{1.65 \times 40000}{8 \times 2490}$$

$$d = 3.3 \text{ ft.}$$

With sag of 3.3 ft. the length of wire

$$L = Y\left(1 + \frac{8}{3}\,\frac{d^2}{Y^2}\right) =$$

$$200\left(1 + \frac{8}{3}\,\frac{3.3^2}{200^2}\right) = 200.145$$

Contraction due to removal of wind and ice:

$$E = \frac{TL}{es}$$

$$= T\,\frac{200.145}{12000000 \times 0.083}$$

$= 0.000201\ T$ (T in this case being the difference in tension.)

Tension	Length	Sag
2,490	200.145	3.3
2,390	200.125	3.06
2,290	200.105	2.80
2,190	200.085	2.52
2,090	200.065	2.21
1,990	200.045	1.84
1,890	200.025	1.37
1,790	200.004	0.55

The sag for each of the above lengths is determined from the formula:

$$d=\sqrt{\frac{3}{8}Y(L-Y)}$$

$$=8.65\sqrt{L-200}$$

Increase in tension due to contraction of wires:

$$d=\frac{wY^2}{8T}$$

$$=\frac{0.323\times 40000}{8T}$$

$$=\frac{1615}{T}$$

Tension	Sag
1,615	1.0
1,700	0.95
1,800	0.9
1,900	0.85

Plotting these two relations of tension and sag with sags as abscissæ and tensions as ordinates, the intersection of the two curves shows the sag and tension at equilibrium.

From the curve:

Sag = 0.89 ft. = 10.7 in.
Tension = 1,820 lb.

Which represents the conditions in the wire at 0° F. without wind or sleet.

To find the sags at other temperatures:

$$a=\frac{1}{54\,cY^2}(d_1^2-d_0^2)+\frac{3}{2}\,\frac{1}{ec}\,\frac{p}{s}\,Y^2\left(\frac{1}{d_0}-\frac{1}{d_1}\right)$$

$$\frac{1}{54\,cY^2}=\frac{1}{54\times 0.0000096\times 40000}=0.0482$$

$$\frac{3}{2}\,\frac{1}{ec}\,\frac{p}{s}\,Y^2=2{,}020$$

Assume variations of 1 in. in the sag,

$d_0 = 10.7$ in. $d_1 = 11.7$ in.

$a = 0.0482\ (22.4) + 2020 \times 0.00799$

$= 1.08 + 16.20 = 17.30$ 17.30

$d_0 = 11.7$ in.	$a = 14.8$	32.1
12.7	12.9	45.0
13.7	11.4	56.4
14.7	10.2	66.6
15.7	9.3	75.9
16.7	8.5	84.4
17.7	7.9	92.3
18.7	7.3	99.6
19.7	6.9	106.5
20.7	6.6	113.1
21.7	6.2	119.3
22.7	6.0	125.3

Plotting with sags as abscissæ and temperatures as ordinates, the sag at any temperature can be read from the curve; for example, the sag at 60° should be 15 in.

SAG OF WIRES

Tables showing the sag at ordinary ranges of temperature for various sizes of stranded copper and aluminum wire to give a factor of safety of 2 at 0° F. under conditions of 70 miles per hour wind velocity and 1/2 in. thickness of sleet on the wires.

NO. 0 STRANDED COPPER

Temp.	Spans in feet								
	100 or less	125	150	200	250	300	400	500	600
	Sags								
	in.	in.	in.	in.	in.	in.	ft.	ft.	ft.
0°	2	4	6	11	23	40	8½	16½	29
30°	2	4	7	13	27	46	9	17	29½
60°	3	5	9	15	32	52	10	17½	30½
90°	3	7	11	19	37	59	10½	18½	31
120°	4	9	14	23	42	67	11½	19	31½

NO. 2/0 STRANDED COPPER

Temp.	Spans in feet								
	100 or less	125	150	200	250	300	400	500	600
	Sags								
	in.	in.	in.	in.	in.	in.	ft.	ft.	ft.
0°	2	3	5	10	18	30	6	11½	19½
30°	2	4	6	11	22	37	7	12½	20½
60°	3	5	7	13	26	44	7½	13½	21½
90°	3	6	9	16	31	51	8½	14	22
120°	4	7	11	19	36	58	9	15	23

NO. 3/0 STRANDED COPPER

Temp.	Spans in feet								
	100 or less	125	150	200	250	300	400	500	600
	Sags								
	in.	in.	in.	in.	in.	in.	in.	ft.	ft.
0°	2	3	4	9	15	24	56	9	15½
30°	2	4	5	10	18	30	64	9½	16½
60°	3	5	6	12	22	36	73	10½	17½
90°	3	6	8	14	27	43	82	11	18½
120°	4	7	10	17	32	50	92	12	19

NO. 4/0 STRANDED COPPER

Temp.	Spans in feet								
	100 or less	125	150	200	250	300	400	500	600
	Sags								
	in.	in.	in.	in.	in.	in.	in.	ft.	ft.
0°	2	3	4	9	12	17	39	6½	12½
30°	2	4	5	10	15	21	44	7	13½
60°	3	5	6	12	18	26	50	8	14½
90°	3	6	8	14	22	31	58	8½	15½
120°	4	7	10	17	26	37	66	9½	16½

NO. 2/0 STRANDED ALUMINUM

Temp.	Spans in feet: 100 or less	125	150	200	250	300	400	500
	Sags							
	in.	in.	in.	ft.	ft.	ft.	ft.	ft.
0°	2	13	25	4½	6½	11½	23½	38
30°	3	15	31	5	7	12	24	38½
60°	6	19	37	5½	7½	12½	24½	39
90°	11	25	42	6	8	13	25	39½
120°	17	32	47	6½	8½	13½	25½	40

NO. 3/0 STRANDED ALUMINUM

Temp.	Spans in feet: 100 or less	125	150	200	250	300	400	500	600
	Sags								
	in.	in.	in	in.	ft.	ft.	ft.	ft.	ft.
0°	2	8	15	33	5	8½	19	32	45
30°	3	10	22	42	5½	9	19½	32½	45½
60°	6	15	28	51	6½	9½	20	33	46
90°	11	21	34	58	7	10	20½	33½	47
120°	17	28	40	64	7½	11	21	34	47½

NO. 4/0 STRANDED ALUMINUM

Temp.	Spans in feet: 100 or less	125	150	200	250	300	400	500	600
	Sags								
	in.	in.	in.	in.	in.	ft.	ft.	ft.	ft.
0°	2	5	10	20	40	6	15	26	37½
30°	3	7	18	30	50	7	16	26½	38
60°	6	11	25	40	59	7½	16½	27½	39
90°	11	18	32	48	67	8½	17½	28	39½
120°	17	27	30	56	75	9	18	28½	40

APPENDIX C

TELEGRAPH CHARACTERS

	Morse	Continental
A	· —	· —
B	— · · ·	— · · ·
C	· · ·	— · — ·
D	— · ·	— · ·
E	·	·
F	· — ·	· · — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	— · — ·	· — — —
K	— · —	— · —
L	⸻	· — · ·
M	— —	— —
N	— ·	— ·
O	· ·	— — —
P	· · · · ·	· — — ·
Q	· · — ·	— — · —
R	· · ·	· — ·
S	· · ·	· · ·

	Morse	Continental
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	· — · ·	— · · —
Y	· · · ·	— · — —
Z	· · · ·	— — · ·
&	· · · ·	
1	· — — ·	· — — — —
2	· · — · ·	· · — — —
3	· · · — ·	· · · — —
4	· · · · —	· · · · —
5	— — —	· · · · ·
6	· · · · · ·	— · · · ·
7	— — · ·	— — · · ·
8	— · · · ·	— — — · ·
9	— · · —	— — — — ·
0	⸻	— — — — —

Short Numerals Generally Used By Continental Operators

1	· —	3	· · · — —	5	·	7	— — · · ·	9	— ·
2	· · —	4	· · · · —	6	— · · · ·	8	— · ·	0	—

		Morse	Continental	Phillips
.	Period	· · — — · ·	· · · · · ·	· · — — · ·
:	Colon	— · — · ·		— · — · ·
:-	Colon Dash			— · — · — · ·
;	Semi-Colon	· — · — ·		· · · · ·
,	Comma	· — · —		· — · —
?	Interrogation	— · · — ·	· · — — · ·	— · · — ·
!	Exclamation	— — — ·	— — · · —	— — — ·
—	Fraction Line	·	— —	·
-	Dash			— · · · — · ·
-	Hyphen		— · · · · —	· · · · · — · ·
'	Apostrophe		· — — — — ·	· · — · · — · ·
£	Pound Sterling			· · · · · · — · ·
/	Shilling		· · ·	· · — —
d	Pence			— · ·
$	Dollars			· · · · — · ·
¢	Cents			· · ·
: "	Colon Followed by Quotation			— · — · · — ·
.	Decimal Point		· — — ·	— · · · · —
¶	Paragraph	— — — — — — ·	— — · —	— — — —
( )	Parenthesis	· — · · —	— · — — · —	· · · · · — ·
[ ]	Brackets			— · · · · — · ·
" "	Quotation		· — · · — ·	· · — · — ·
	Quotation within a Quotation			· · — · · — · ·
	End of Quotation		· — · · — ·	· · — · — · — ·
	End of Quotation within Quotation			· · — · · · · ·
	Percent		— — — · · · — — —	· · · · · · ·
	Capitalized Letter			· · · · — · ·
	Italics or Underline		· — · · · — · ·	· · — · — · ·

APPENDIX D

USEFUL TABLES

COIL-WINDINGS, RESISTANCE, AND OPERATING CURRENT OF TELEGRAPH INSTRUMENTS

Instrument	Resistance, ohms	Turns of wire	Gage of wire, B. & S.	Normal operating current, mil-amperes
Single line relay......	75	2,350 per spool.....	29, single silk......	80
Single line relay......	150	3,600 per spool....	30, single silk......	40
Single line relay......	250	3,900 per spool....	32, single silk......	25
Sounder.............	10	1,080 per spool....	24, cotton.........	250
Sounder.............	150	3,500 per spool....	33, single silk......	50
Polar relay...........	100	1,600 per section...	29, single silk......	20
Polar relay...........	200	1,400 per section...	32, single silk......	20
Polar relay...........	300	1,800 per section...	33, enameled......	20
Polar relay...........	500	2,500 per section...	34, single silk......	20
Neutral relay.........	60	1,400 per section...	30, single silk......	60
Neutral relay.........	140	1,600 per section...	33, single silk......	60
Transmitter..........	20	1,240 per spool.....	26, single silk......	200
Transmitter..........	150	3,600 per spool....	30, single silk......	50

WIRE GAGES

Brown & Sharpe's Gage

The B. & S. Gage is standard for copper wire and is understood to apply to all cases where size of copper wire is mentioned in any wire gage number.

By referring to table it will be seen that in the B. & S. Gage, to all practical purposes, the area in circular mils is doubled for every third size heavier, by gage number, and halved for every third size lighter, by gage number.

Every tenth size heavier by gage number has ten times the area in circular mills.

Every 10 B. & S. Gage wire has an area of approximately 10,000 circular mils, and from this base the other sizes can be figured, if a table should not be at hand.

WIRE GAGES

Iron wire Mile ohm at 60° Fahr. is 4500 lbs. 100% pure.
H. D. Copper wire " " " " " " 859 " " "

Birmingham Gage	Diameter Mils	IRON		American Gage	Diameter Mils	IRON		American Gage	Diameter Mils	H. D. COPPER 97.95% Conductivity	
		Weight, Lbs. Per Mile	Resistance, 60° F. Ohms			Weight, Lbs. Per Mile	Resistance, 60° F. Ohms			Weight, Lbs. Per Mile	Resistance, 60° F. Ohms
....	....	....	....	2	258	932	4.99	2	258	1064	.825
3	258	932	4.99	3	229	729	6.38	3	229	838	1.04
4	238	787	5.97	4	204	578	8.05	4	204	665	1.32
5	220	673	6.98	5	182	460	10.11	5	182	529	1.65
6	203	573	8.20	6	162	364	12.79	6	162	419	2.09
7	180	450	10.44	7	144	288	16.16	7	144	331	2.65
8	165	378	12.43	8	128	228	20.41	8	128	262	3.35
9	148	305	15.41	9	114	181	25.71	9	114	208	4.22
10	134	250	18.80	10	102	145	32.10	10	102	166	5.28
11	120	200	23.50	11	91	115	40.47	11	91	132	6.65
12	109	165	28.48	12	81	91	51.15	12	81	105	8.36
13	95	125	37.60	13	72	72	64.65	13	72	83	10.55
14	83	95	49.47	14	64	....	....	14	64	65	13.29
15	72	72	65.27	15	57	....	....	15	57	52	16.78
....	....	....	....	16	51	....	....	16	51	42	21.15
....	....	....	....	17	45	....	....	17	45	32	26.69
....	....	....	....	18	40	....	....	18	40	26	33.63
....	....	....	....	....	....	....	....	19	35	20	42.58
....	....	....	....	....	....	....	....	20	32	16	53.63

Classification of Gages

In addition to the confusion caused by a multiplicity of wire gages, several of them are known by various names.

For example:

Brown & Sharpe (B. & S.) = American Wire Gage (A. W. G.).

New British Standard (N. B. S.) = British Imperial, English Legal Standard and Standard Wire Gage and is variously abbreviated by S. W. G. and I. W. G.

Birmingham Gage (B. W. G.) = Stubs', Old English Standard and Iron Wire Gage.

Roebling = Washburn Moen, American Steel and Wire Co.'s Iron Wire Gage.

London = Old English (not Old English Standard).

As a further complication:

Birmingham or Stubs' Iron Wire Gage is not the same as Stubs' Steel Wire Gage.

General Uses of Various Gages

B. & S. G.—All forms of round wires used for electrical conductors. Sheet copper, brass and German silver.

U. S. S. G.—Sheet iron and steel. Legalized by act of Congress, March 3, 1893.

B. W. G.—Galvanized iron wire. Norway iron wire.

American Screw Co.'s Wire Gage.—Numbered sizes of machine and wood screws, particularly up to No. 14 (0.2421 in.).

Stubs' Steel Wire Gage.—Drill rod.

Roebling & Trenton.—Iron and steel wire. Telephone and telegraph wire.

N. B. S.—Hard drawn copper. Telephone and telegraph wire.

London Gage.—Brass wire.

EQUIVALENTS OF WIRES—B. & S. GAGE

0000	=	2–0	=	4–3	=	8–6	=	16–9	=	32–12	=	64–15
000	=	2–1	=	4–4	=	8–7	=	16–10	=	32–13	=	64–16
00	=	2–2	=	4–5	=	8–8	=	16–11	=	32–14	=	64–17
0	=	2–3	=	4–6	=	8–9	=	16–12	=	32–15		.....
1	=	2–4	=	4–7	=	8–10	=	16–13	=	32–16		.....
2	=	2–5	=	4–8	=	8–11	=	16–14	=	32–17		.....
3	=	2–6	=	4–9	=	8–12	=	16–15	=	32–18		.....
4	=	2–7	=	4–10	=	8–13	=	16–16		.....		.....
5	=	2–8	=	4–11	=	8–14	=	16–17		.....		.....
6	=	2–9	=	4–12	=	8–15	=	16–18		.....		.....
7	=	2–10	=	4–13	=	8–16		.....		.....		.....
8	=	2–11	=	4–14	=	8–17		.....		.....		.....
9	=	2–12	=	4–15	=	8–18		.....		.....		.....
10	=	2–13	=	4–16		....		.....		.....		.....
11	=	2–14	=	4–17		....		.....		.....		.....
12	=	2–15	=	4–18		....		.....		.....		.....
13	=	2–16	=	4–19		....		.....		.....		.....
14	=	2–17		....		....		.....		.....		.....
15	=	2–18		....		....		.....		.....		.....
16	=	2–19		....		....		.....		.....		.....

CURRENT REQUIRED TO FUSE WIRES OF COPPER, GERMAN SILVER AND IRON

B. & S. gage	Copper, amperes	German silver, amperes	Iron, amperes	B. & S. gage	Copper, amperes	German silver, amperes	Iron, amperes
10	333.	169.	101.	26	20.6	10.6	6.22
11	284.	146.	86.	27	17.7	9.1	5.36
12	235.	120.7	71.2	28	14.7	7.5	4.45
13	200.	102.6	63.	29	12.5	6.41	3.79
14	166.	85.2	50.2	30	10.25	5.26	3.11
15	139.	71.2	42.1	31	8.75	4.49	2.65
16	117.	60.0	35.5	32	7.26	3.73	2.2
17	99.	50.4	32.6	33	6.19	3.18	1.88
18	82.8	42.5	25.1	34	5.12	2.64	1.55
19	66.7	34.2	20.2	35	4.37	2.24	1.33
20	58.3	29.9	17.7	36	3.62	1.86	1.09
21	49.3	25.3	14.9	37	3.08	1.58	.93
22	41.2	21.1	12.5	38	2.55	1.31	.77
23	34.5	17.7	10.9	39	2.20	1.13	.67
24	28.9	14.8	8.76	40	1.86	.95	.56
25	24.6	12.6	7.46				

THERMOMETER SCALES

Centigrade	Fahrenheit	Centigrade	Fahrenheit	Centigrade	Fahrenheit
100	212.0	66	150.8	32	89.6
99	210.2	65	149.0	31	87.8
98	208.4	64	147.2	30	86.0
97	206.6	63	145.4	29	84.2
96	204.8	62	143.6	28	82.4
95	203.0	61	141.8	27	80.6
94	201.2	60	140.0	26	78.8
93	199.4	59	138.2	25	77.0
92	197.6	58	136.4	24	75.2
91	195.8	57	134.6	23	73.4
90	194.0	56	132.8	22	71.6
89	192.2	55	131.0	21	69.8
88	190.4	54	129.2	20	68.0
87	188.6	53	127.4	19	66.2
86	186.8	52	125.6	18	64.4
85	185.0	51	123.8	17	62.6
84	183.2	50	122.0	16	60.8
83	181.4	49	120.2	15	59.0
82	179.6	48	118.4	14	57.2
81	177.8	47	116.6	13	55.4
80	176.0	46	114.8	12	53.6
79	174.2	45	113.0	11	51.8
78	172.4	44	111.2	10	50.0
77	170.6	43	109.4	9	48.2
76	168.8	42	107.6	8	46.4
75	167.0	41	105.8	7	44.6
74	165.2	40	104.0	6	42.8
73	163.4	39	102.2	5	41.0
72	161.6	38	100.4	4	39.2
71	159.8	37	98.6	3	37.4
70	158.0	36	96.8	2	35.6
69	156.2	35	95.0	1	33.8
68	154.4	34	93.2	0	32.0
67	152.6	33	91.4		

Seventy-five degrees Fahrenheit, or 23.8° C. is the standard temperature for measuring electrical resistances in submarine cable tests.

Sixty degrees Fahrenheit, or 15.5° C., is the standard temperature for measuring the electrical resistance of wire for general telegraphic purposes.

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